Message

From: Dean, Heather [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=544264942F0644FEAF7C86ABAEBCD3DF-DEAN, HEATHER]
Sent: 5/27/2016 12:36:26 AM
To: Meyer, Susan [meyer.susan@epa.gov]; Murchie, Peter [Murchie.Peter@epa.gov]; Szalay, Endre [Szalay.Endre@epa.gov]; Michael Szerlog [Szerlog.Michael@epa.gov]
CC: David Allnutt [Allnutt.David@epa.gov]
Subject: Data Availability for High Tide Line Options
Attachments: Data Availability for High Tide Line Options.pptx

Happy Long Weekend Eve!

In response to discussions we've had about tidal data availability & the need for extrapolation between tide stations—which also came up during this week's briefing—I have prepared the maps shown in the attached file. They depict the number & location of tide stations for which data is either readily available or just about so for using HAT, MHHW, or MHPT. (The second map from the left is the only one in the "just about so" category. It adds five stations that already have harmonic constituents, where calculating HAT should, seemingly, be pretty easy, I've got a question into NOS about that.)

In a nutshell, for:

- HAT, there are 43 to 48 stations;
- MHHW, there are 85 stations; &
- MHPT, there are 171 stations.

If you have any questions on Friday, please call, rather than e-mailing. (I'll be off, but am happy to answer any questions.)

If not, see you Tuesday!

Heather

From: Dean, Heather [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=544264942F0644FEAF7C86ABAEBCD3DF-DEAN, HEATHER]
Sent: 9/17/2015 10:49:26 PM
To: Szerlog, Michael [Szerlog.Michael@epa.gov]

Subject: Accepted: High Tide Line Discussion
Location: Teleconfernce and Adobe Connect

Start: 9/24/2015 9:00:00 PM
End: 9/24/2015 10:00:00 PM
Show Time As: Busy

Appointment

From: Dean, Heather [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=544264942F0644FEAF7C86ABAEBCD3DF-DEAN, HEATHER]
Sent: 5/11/2016 6:01:52 PM
To: Meyer, Susan [meyer.susan@epa.gov]

Subject: Accepted: discuss field proceedures for HTL- internal- probably won't need whole hour
Location: phone or Heather and Tim together

Start: 5/11/2016 8:30:00 PM
End: 5/11/2016 9:30:00 PM
Show Time As: Busy

Message

From: Dean, Heather [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=544264942F0644FEAF7C86ABAEBCD3DF-DEAN, HEATHER]
Sent: 2/3/2016 9:16:07 PM
To: Donna Downing [Downing.Donna@epa.gov]
Subject: Checking In on HTL

Hi, Donna.

At the behest of Dennis & the Seattle District Engineer (Col. Buck), we have started meeting with the District & NOAA to attempt to resolve the HTL issue out here. Our initial meeting was last week, & we are going to meet every two weeks to try to have an agreement (on at least a plan or moving forward) by mid-June (Dennis' directive). Deliberative Process / Ex. 5

Deliberative Process / Ex. 5

Thanks,

Heather

Message

From: Dean, Heather [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=544264942F0644FEAF7C86ABAEBCD3DF-DEAN, HEATHER]
Sent: 7/26/2016 3:20:49 PM
To: Dean, Heather [Dean.Heather@epa.gov]
Subject: RE: High Tide Line Maps
Attachments: Elevation Tables.pptx

Hi, Tim.

Deliberative Process / Ex. 5

Deliberative Process / Ex. 5 Let me know if you have any issues or questions.

Thanks,

Heather

From: Dean, Heather
Sent: Monday, July 25, 2016 3:00 PM
To: Siwiec, Tim <Siwiec.Tim@epa.gov>
Subject: High Tide Line Maps

Hi, Tim. **Deliberative Process / Ex. 5**
Deliberative Process / Ex. 5 To that end, I have a few requested revisions, as well as a couple of questions. Here they are:

Deliberative Process / Ex. 5

Deliberative Process / Ex. 5

Let me know if you have any questions or issues.

Thanks!

Heather

Message

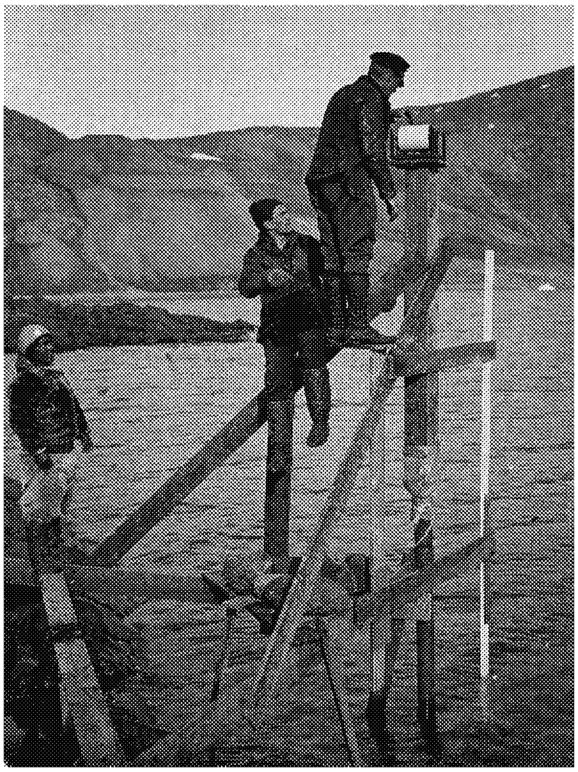
From: Dean, Heather [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=544264942F0644FEAF7C86ABAEBCD3DF-DEAN, HEATHER]
Sent: 3/9/2016 3:41:55 PM
To: Michael Szerlog [Szerlog.Michael@epa.gov]
Subject: HTL Meeting
Attachments: WA Harmonic Stations.xlsx; NOAA Glossary.pdf; HTLvsMHHW.xlsx; Datums-Washington.pptx; Tide Station Data-7 Mar 16.xlsx; Graphic-Corps Datums (with MHW)-updated 7 Mar 16.pptx; HTL Matrix for WA Workgroup.docx; fantastic_tidal_datums.pdf

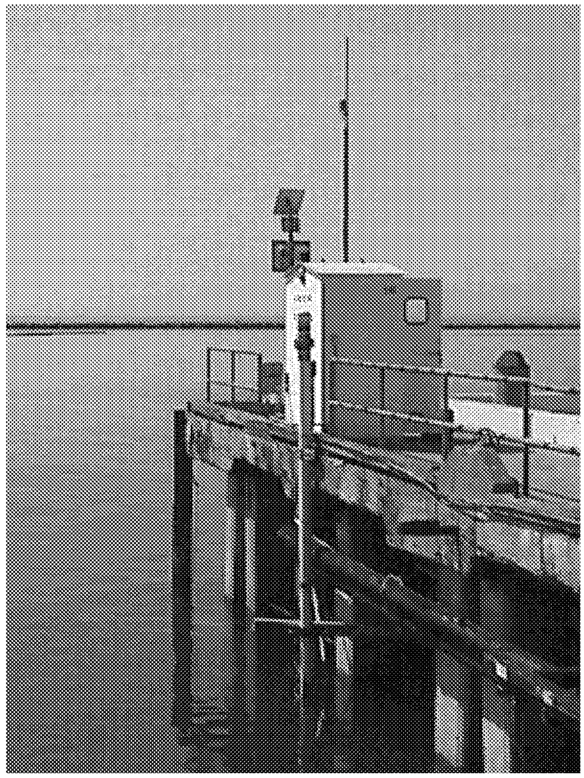
Good morning. Jim asked if we could use Adobe Connect to view materials again today. I intend to drive that myself, but am forwarding them to you, in case technology has other ideas. The comic book is attached so we can start with it! ;-)

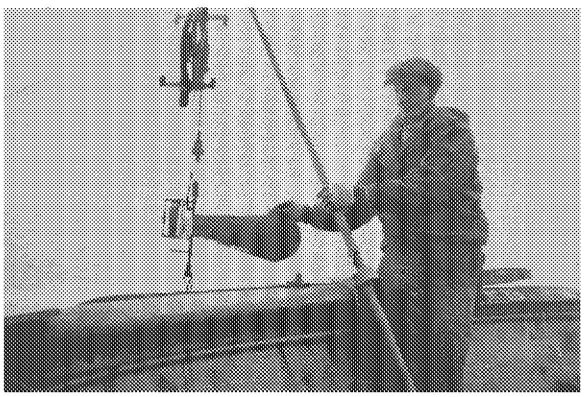
Thanks,

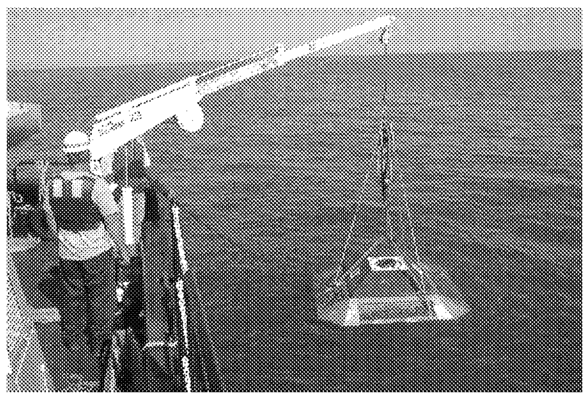
Heather

Tide and Current Glossary









Silver Spring, MD
January 2000

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Service
Center for Operational Oceanographic Products and Services

Tide and Current Glossary

U.S. DEPARTMENT OF COMMERCE
Norman Mineta, Secretary

National Oceanic and Atmospheric Administration
D. James Baker, Administrator

National Ocean Service
Margaret Davidson, Assistant Administrator

Center for Operational Oceanographic Products and Services
David M. Kennedy, Acting Director

Preface to 1999 Edition

The publication is a revision of the 1989 edition. This edition has been a group effort by Steacy D. Hicks, Richard L. Sillcox, C. Reid Nichols, Brenda Via, and Evette C. McCray. It was subsequently revised by Chris Zervas. Final formatting, layout, and printing has been under the authority of Brenda Via.

The author wishes to thank the following for their contributions: C. Reid Nichols (numerous entries), Richard L. Sillcox, Jack E. Fancher, Dr. Robert G. Williams, Thomas J. Kendrick, Douglas M. Martin, David B. Zilkoski, Richard Edwing, Michael Szabados, Steven Lyles, James Hubbard, Michael Gibson, Steven Gill, William Stoney, Dr. Ledolph Baer, and Dr. Bruce B. Parker. Special thanks is given to Dr. Kurt Hess for his numerous technical corrections and suggestions.

Printing History of Tide and Current Glossary

Special Publication No. 228, Coast and Geodetic Survey, by Paul Schureman, 1941.

Special Publication No. 228, Coast and Geodetic Survey, by Paul Schureman revised by E. C. McKay and F. J. Haight, 1949.

Special Publication No. 228, Coast and Geodetic Survey, by Paul Schureman, reprinted with corrections, 1963.

National Ocean Survey, by Paul Schureman, revised by Steacy D. Hicks, 1975.

National Ocean Service, by Steacy D. Hicks, 1984.

National Ocean Service, by Steacy D. Hicks, 1989.

National Ocean Service, by Steacy D. Hicks, 1999.

For further information on tides, sea level, tidal datums, record certifications, and related publications, contact:

NOAA, National Ocean Service
CO-OPS, Products and Services N/OPS3
Attn: User Services
1305 East-West Highway
Silver Spring, MD 20190-3281

Phone: (301)713-2877 Ext. 176
Fax: (301)713-4437

For further information on Great Lakes water levels, datums, and related publications, contact:

NOAA, National Ocean Service
CO-OPS, Requirements and Development N/OPS1
Attn: Great Lakes
1305 East-West Highway
Silver Spring, MD 20910-3281

Phone: (301)713-2902 Ext. 184
Fax: (301)713-4435

For further information on currents, tide and tidal current predictions, and related publications, contact:

NOAA, National Ocean Service
CO-OPS, Products and Services N/OPS3
Attn: Tidal Predictions
1305 East-West Highway
Silver Spring, MD 20910-3281

Phone: (301)713-2815 Ext. 119
Fax: (301)713-4500

Tide and Current Glossary

A

absolute mean sea level change—An eustatic change in mean sea level relative to a conventional terrestrial coordinate system with the origin at the center of mass of the Earth.

accepted values—Tidal datums and Greenwich high and low water intervals obtained through primary determination or comparison of simultaneous observations with a control tide station in order to derive the equivalent value that would be obtained with a 19-year series.

acoustic Doppler current profiler (ADCP)—A current measuring instrument employing the transmission of high frequency acoustic signals in the water. The current is determined by a Doppler shift in the backscatter echo from plankton, suspended sediment, and bubbles, all assumed to be moving with the mean speed of the water. Time gating circuitry is employed which uses differences in acoustic travel time to divide the water column into range intervals, called bins. The bin determinations allow development of a profile of current speed and direction over most of the water column. The ADCP can be deployed from a moving vessel, tow, buoy, or bottom platform. In the latter configuration, it is nonobtrusive in the water column and thus can be deployed in shipping channels.

ADR gauge—Analog to Digital Recording water level gauge. A float or pressure-actuated water level gauge that records heights at regular time intervals in digital format.

age of diurnal inequality—The time interval between the maximum semimonthly north or south declination of the Moon and the maximum effect of declination upon range of tide or speed of the tidal current. The age may be computed from the harmonic constants by the formula:
age of diurnal inequality = $0.911(K_1° - O_1°)$ hours.

age of Moon—The time elapsed since the preceding new Moon

age of parallax inequality—The time interval between perigee of the Moon and the maximum effect of parallax upon range of tide or speed of the tidal current. This age may be computed from the harmonic constants by the formula:
age of parallax inequality = $1.837(M_2° - N_2°)$ hours.

age of phase inequality—The time interval between new or full Moon and the maximum effect of these phases upon range of tide or speed of the tidal current. This age may be computed from the harmonic constants by the formula:
age of phase inequality = $0.984(S_2° - M_2°)$ hours.

age of tide—Same as age of phase inequality.

agger—Same as double tide.

Agulhas Current—An Indian Ocean current setting southwestward along the southeast coast of Africa.

air acoustic ranging sensor—A pulsed, acoustic ranging device using the air column in a tube as the acoustic sound path. The fundamental measurement is the time it takes for the acoustic signal to travel from a transmitter to the water surface and then back to the receiver. The distance from a reference point to the water surface is derived from the travel time. A calibration point is set at a fixed distance from the acoustic transducer and is used to correct the measured distance using the calibrated sound velocity in the tube. Air temperature sensors are located in the protective well for the purpose of verifying uniformity of temperature for measurements taken by the air acoustic ranging sensor.

Alaska Current—A North Pacific Ocean current setting counterclockwise along the coasts of Canada and Alaska in the Gulf of Alaska.

Alaskan Stream—A North Pacific Ocean current setting westward along the south side of the Aleutian Islands. It is an extension of the Alaska Current.

amphidromic point—A point of zero amplitude of the observed or a constituent tide.

amphidromic region—An area surrounding an amphidromic point from which the radiating cotidal lines progress through all hours of the tidal cycle.

amplitude (H)—One-half the range of a constituent tide. By analogy, it may be applied also to the maximum speed of a constituent current.

analog—A continuous measurement or a continuous graphic display of data. See ADR gauge and marigram.

analysis, harmonic—See harmonic analysis.

analyzer, harmonic—See harmonic analyzer.

angular velocity of the Earth's rotation (Ω)—Time rate of change of angular displacement relative to the fixed stars. It is equal to $0.729,211 \times 10^{-4}$ radian/second.

annual inequality—Seasonal variation in water level or current, more or less periodic, due chiefly to meteorological causes.

anomalistic—Pertaining to the periodic return of the Moon to its perigee or the Earth to its perihelion. The anomalistic month is the average period of the revolution of the Moon around the Earth with respect to lunar perigee, and is approximately 27.554,550 days in length. The anomalistic year is the average period of the revolution of the Earth around the Sun with respect to perihelion, and is approximately 365.259,6 days in length.

anomaly—As applied to astronomy, the anomaly is the angle made at any time by the radius vector of a planet or moon with its line of apsides, the angle being reckoned from perihelion or perigee in the direction of the body's motion. It is called the true anomaly when referred to the actual position of the body, and mean anomaly when referred to a fictitious body moving with a uniform angular velocity equal to the average velocity of the real body and passing perihelion or perigee at the same time.

Antarctic Circumpolar Current—The largest permanent current in the world, setting eastward around the Antarctic Continent south of Cape Horn, Cape of Good Hope, Tasmania, and New Zealand. Through Drake Passage, it transports approximately 200 x 10^6 m^3/s. Same as West Wind Drift.

anticyclonic ring—A meander breaking off from the main oceanic current and spinning in a clockwise direction in the northern hemisphere (counter-clockwise in southern).

Antilles Current—A North Atlantic Ocean current setting northwestward along the northeast coasts of the Bahama Islands.

aphelion—The point in the orbit of the Earth (or other planet, etc.) farthest from the Sun.

apogean tides or tidal currents—Tides of decreased range or currents of decreased speed occurring monthly as the result of the Moon being in apogee. The apogean range (An) of the tide is the average range occurring at the time of apogean tides and is most conveniently computed from the harmonic constants. It is smaller than the mean range, where the type of tide is either semidiurnal or mixed, and is of no practical significance where the type of tide is predominantly diurnal.

apogee—The point in the orbit of the Moon or a man-made satellite farthest from the Earth. The point in the orbit of a satellite farthest from its companion body.

apparent secular trend—The nonperiodic tendency of sea level to rise, fall, or remain stationary with time. Technically, it is frequently defined as the slope of a least-squares line of regression through a relatively long series of yearly mean sea-level values. The word "apparent" is used since it is often not possible to know whether a trend is truly nonperiodic or merely a segment of a very long oscillation (relative to the length of the series).

apparent time—Time based upon the true position of the Sun as distinguished from mean time, which is measured by a fictitious Sun moving at a uniform rate. Apparent time is that shown by the sundial, and its noon is the time when the Sun crosses the meridian. The difference between apparent time and mean time is known as the equation of time. Although quite common many years ago, apparent time is seldom used now.

apsides—The points in the orbit of a planet or moon which are the nearest and farthest from the center of attraction. In the Earth's orbit these are called perihelion and aphelion, and in the Moon's orbit, perigee and apogee. The line passing through the apsides of an orbit is called the line of apsides.

argument—See equilibrium argument.

astres fictifs—Fictitious celestial bodies which are assumed to move in the celestial equator at uniform rates corresponding to the speeds of the several harmonic constituents of the tide producing force. Each astre fictif crosses the meridian at a time corresponding to the maximum of the constituent that it represents.

astronomical day—See astronomical time.

astronomical tide—Same as tide.

astronomical time—Time formerly used in astronomical calculations in which the day began at noon rather than midnight. The astronomical day commenced at noon of the civil day of the same date. The hours of the day were numbered consecutively from zero (noon) to 23 (11 a.m. of the following morning). Up to the close of the year 1924, astronomical time was in general use in nautical almanacs. Beginning with the year 1925, the American Ephemeris and Nautical Almanac and similar publications of other countries abandoned the old astronomical time and adopted Greenwich civil (mean) time for the data given in their tables.

augmenting factor—A factor, used in connection with the harmonic analysis of tides or tidal currents by stencils, to allow for the fact that the tabulated hourly heights or speeds used in the summation for any constituent, other than S, do not in general occur on the exact constituent hours to which they are assigned, but may differ from the same by as much as a half hour.

automatic tide (water level) gauge—An instrument that automatically registers the rise and fall of the water level. In some instruments, the registration is accomplished by recording the heights at regular time intervals in digital format; in others, by a continuous graph of height against time.

azimuth—Azimuth of a body is the arc of the horizon intercepted between the north or south point and the foot of the vertical circle passing through the body. It is reckoned in degrees from either the north or south point clockwise entirely around the horizon. Azimuth of a current is the direction toward which it is flowing, and is usually reckoned from the north point.

B

baroclinic—The condition and type of motion when isobaric surfaces of a fluid are not parallel with isopycnal surfaces.

barotropic—The condition and type of motion when isobaric surfaces of a fluid are parallel with isopycnal surfaces.

barycenter—The common center of mass of the Sun-Earth System or the Moon-Earth System. The distance from the center of the Sun to the Sun-Earth barycenter is about 280 miles. The distance from the center of the Earth to the Moon-Earth barycenter is about 2,895 miles.

bench mark (BM)—A fixed physical object or mark used as reference for a horizontal or vertical datum. A tidal bench mark is one near a tide station to which the tide staff and tidal datums are referred. A primary bench mark is the principal mark of a group of tidal bench marks to which the tide staff and tidal datums are referred. The standard tidal bench mark of the National Ocean Service is a brass, bronze, or aluminum alloy disk 3-½ inches in diameter containing the inscription NATIONAL OCEAN SERVICE together with other individual identifying information. A geodetic bench mark identifies a surveyed point in the National Spatial Reference System. Bench mark disks of either type may, on occasion, serve simultaneously to reference both tidal and geodetic datums. Numerous bench marks of predecessor organizations to NOS, or parts of other organizations absorbed into NOS, still bear the inscriptions: U.S. COAST & GEODETIC SURVEY, NATIONAL GEODETIC SURVEY, NATIONAL OCEAN SURVEY, U.S. LAKE SURVEY, CORPS OF ENGINEERS, and U.S. ENGINEER OFFICE.

Benguela Current—A South Atlantic Ocean current setting northward along the southwest coast of Africa.

bore—Same as tidal bore.

Brazil Current—A South Atlantic Ocean current setting southwestward along the central coast of South America.

bubbler tide (water level) gauge—Same as gas purged pressure gauge.

C

California Current—A North Pacific Ocean current setting southeastward along the west coast of the United States and Baja California.

Callippic cycle—A period of four Metonic cycles equal to 76 Julian years, or 27,759 days. Devised by Callippus, a Greek astronomer, about 350 B.C., as a suggested improvement on the Metonic cycle for a period in which new and full Moon would recur on the same day of the year. Taking the length of the synodical month as 29.530,588 days, there are 940 lunations in the Callippic cycle, with about 0.25 day remaining.

Canary Current—A North Atlantic Ocean current setting southward off the west coast of Portugal and along the northwest coast of Africa.

celestial sphere—An imaginary sphere of infinite radius concentric with the Earth on which all celestial bodies except the Earth are imagined to be projected.

centibar—The unit of pressure equal to 1 metric ton (1000 kilograms) per meter per second per second. See decibar.

chart datum—The datum to which soundings on a chart are referred. It is usually taken to correspond to a low-water elevation, and its depression below mean sea level is represented by the symbol Z_0. Since 1980, chart datum has been implemented to mean lower low water for all marine waters of the United States, its territories, Commonwealth of Puerto Rico, and Trust Territory of the Pacific Islands. See datum and National Tidal Datum Convention of 1980.

Charybdis—Same as Galofaro.

chlorinity (Cl)—The total amount in grams of chlorine, bromine, and iodine contained in one kilogram of seawater, assuming the bromine and iodine to be replaced by chlorine. The number giving the chlorinity in grams per kilogram of a seawater sample is identical with the number giving the mass in grams of atomic weight silver just necessary to precipitate the halogens in 0.328,523,3 kilogram of the seawater sample.

$S(‰) = 1.806{,}55 \times Cl(‰)$

where S(‰) is the salinity in parts per thousand. See salinity.

civil day—A mean solar day commencing at midnight.

civil time—Time in which the day begins at midnight as distinguished from the former astronomical time in which the day began at noon.

classification—See type of tide.

Coast and Geodetic Survey—A former name of the National Ocean Service. The organization was known as: Survey of the Coast from its founding in 1807 to 1836, Coast Survey from 1836 to 1878, Coast and Geodetic Survey from 1878 to 1970, and National Ocean Survey from 1970 to 1982. In 1982 it was named National Ocean Service. From 1965 to 1970, the Coast and Geodetic Survey was a component of the Environmental Science Services Administration (ESSA). The National Ocean Survey was a component of the National Oceanic and Atmospheric Administration (NOAA). NOAA became the successor to ESSA in 1970. The National Ocean Service is a component of NOAA, U.S. Department of Commerce.

coast line—The low water datum line for purposes of the Submerged Lands Act (Public Law 31). See shoreline.

coastal boundary—The mean high water line (MHWL) or mean higher high water line (MHHWL) when tidal lines are used as the coastal boundary. Also, lines used as boundaries inland of and measured from (or points thereon) the MHWL or MHHWL. See marine boundary.

coastal zone (legal definition for coastal zone management)—The term coastal zone means the coastal waters (including the lands therein and thereunder) and the adjacent shorelands (including the waters therein and thereunder), strongly influenced by each and in proximity to the shorelines of the several coastal states, and includes islands, transitional and intertidal areas, salt marshes, wetlands, and beaches. The zone extends, in Great Lakes waters, to the international boundary between the United States and Canada and in other areas seaward to the outer limit of the United States territorial sea. The zone extends inland from the shorelines only to the extent necessary to control shorelands, the uses of which have a direct and significant impact on the coastal waters. Excluded from the coastal zone are lands the use of which is by law subject solely to the discretion of or which is held in trust by the Federal Government, its officers, or agents.

coastline—Same as shoreline. See coast line.

cocurrent line—A line on a map or chart passing through places having the same current hour.

comparison of simultaneous observations—A reduction process in which a short series of tide or tidal current observations at any place is compared with simultaneous observations at a control station where tidal or tidal current constants have previously been determined from a long series of observations. The observations are typically high and low tides and monthly means. For tides, it is usually used to adjust constants from a subordinate station to the equivalent value that would be obtained from a 19-year series. See first reduction, standard method, modified-range ratio method, and direct method.

compass direction—Direction as indicated by compass without any correction for compass error. The direction indicated by a compass may differ by a considerable amount from true or magnetic direction.

compass error—The angular difference between a compass direction and the corresponding true direction. The compass error combines the effects of deviation and variation.

component—(1) Same as constituent. (2) That part of a tidal current velocity which, by resolution into orthogonal vectors, is found to flow in a specified direction.

compound tide—A harmonic tidal (or tidal current) constituent with a speed equal to the sum or difference of the speeds of two or more elementary constituents. The presence of compound tides is usually attributed to shallow water conditions.

constants, current—See current constants.

constants, harmonic—See harmonic constants.

constants, tidal—See tidal constants.

constituent—One of the harmonic elements in a mathematical expression for the tide-producing force and in corresponding formulas for the tide or tidal current. Each constituent represents a periodic change or variation in the relative positions of the Earth, Moon, and Sun. A single constituent is usually written in the form $y = A \cos (at + \alpha)$, in which y is a function of time as expressed by the symbol t and is reckoned from a specific origin. The coefficient A is called the amplitude of the constituent and is a measure of its relative importance. The angle $(at + \alpha)$ changes uniformly and its value at any time is called the phase of the constituent. The speed of the constituent is the rate of change in its phase and is represented by the symbol a in the formula. The quantity α is the phase of the constituent at the initial instant from which the time is reckoned. The period of the constituent is the time required for the phase to change through 360° and is the cycle of the astronomical condition represented by the constituent.

constituent day—The time of the rotation of the Earth with respect to a fictitious celestial body representing one of the periodic elements in the tidal forces. It approximates in length the lunar or solar day and corresponds to the period of a diurnal constituent or twice the period of a semidiurnal constituent. The term is not applicable to the long-period constituents.

constituent hour—One twenty-fourth part of a constituent day.

control current station—A current station at which continuous velocity observations have been made over a minimum period of 29 days. Its purpose is to provide data for computing accepted values of the harmonic and nonharmonic constants essential to tidal current predictions and circulatory studies. The data series from this station serves as the control for the reduction of relatively short series from subordinate current stations through the method of comparison of simultaneous observations. See current station and subordinate current station (1).

control station—See primary control tide station, secondary control tide station, and control current station.

corange line—A line passing through places of equal tidal range.

Coriolis force—A fictional force in the hydrodynamic equations of motion that takes into account the effect of the Earth's rotation on moving objects (including air and water) when viewed with reference to a coordinate system attached to the rotating Earth. The horizontal component is directed 90° to the right (when looking in the direction of motion) in the Northern Hemisphere and 90° to the left in the Southern. The horizontal component is zero at the Equator; also, when the object is at rest relative to the Earth. The Coriolis acceleration = $2v\Omega \sin ø$: where v is the speed of the object, Ω is the angular velocity of the Earth, and ø is the latitude. Named for Gaspard Gustave de Coriolis who published his formulation in 1835.

corrected current—A relatively short series of current observations from a subordinate station to which a factor is applied to adjust the current to a more representative value based on a relatively long series from a nearby control station. See current and total current.

cotidal hour—The average interval between the Moon's transit over the meridian of Greenwich and the time of the following high water at any place. This interval may be expressed either in solar or lunar time. When expressed in solar time, it is the same as the Greenwich high water interval. When expressed in lunar time, it is equal to the Greenwich high water interval multiplied by the factor 0.966.

cotidal line—A line on a chart or map passing through places having the same tidal hour.

countercurrent—A current usually setting in a direction opposite to that of a main current. See Equatorial Countercurrent.

crest—The highest point in a propagating wave. See high water and tidal wave.

current—Generally, a horizontal movement of water. Currents may be classified as tidal and nontidal. Tidal currents are caused by gravitational interactions between the Sun, Moon, and Earth and are part of the same general movement of the sea that is manifested in the vertical rise and fall, called tide. Tidal currents are periodic with a net velocity of zero over the particular tidal cycle. See tidal wave. Nontidal currents include the permanent currents in the general circulatory systems of the sea as well as temporary currents arising from more pronounced meteorological variability. Current, however, is also the British equivalent of our nontidal current. See total current.

current constants—Tidal current relations that remain practically constant for any particular locality. Current constants are classified as harmonic and nonharmonic. The harmonic constants consist of the amplitudes and epochs of the harmonic constituents, and the nonharmonic constants include the velocities and intervals derived directly from the current observations.

current curve—A graphic representation of the flow of the current. In the reversing type of tidal current, the curve is referred to rectangular coordinates with time represented by the abscissa and the speed of the current by the ordinate, the flood speeds being considered as positive and the ebb speeds as negative. In general, the current curve for a reversing tidal current approximates a cosine curve.

current diagram—A graphic table published in the Tidal Current Tables showing the speeds of the flood and ebb currents and the times of slacks and strengths over a considerable stretch of the channel of a tidal waterway, the times being referred to tide or tidal current phases at some reference station.

current difference—Difference between the time of slack water (or minimum current) or strength of current in any locality and the time of the corresponding phase of the tidal current at a reference station for which predictions are given in the Tidal Current Tables.

current direction—Same as set.

current ellipse—A graphic representation of a rotary current in which the velocity of the current at different hours of the tidal cycle is represented by radius vectors and vectoral angles. A line joining the extremities of the radius vectors will form a curve roughly approximating an ellipse. The cycle is completed in one-half tidal day or in a whole tidal day, according to whether the tidal current is of the semidiurnal or the diurnal type. A current of the mixed type will give a curve of two unequal loops each tidal day.

current hour—The mean interval between the transit of the Moon over the meridian of Greenwich and the time of strength of flood, modified by the times of slack water (or minimum current) and strength of ebb. In computing the mean current hour, an average is obtained of the intervals for the following phases: flood strength, slack (or minimum) before flood increased by 3.10 hours (one-fourth of tidal cycle), slack (or minimum) after flood decreased by 3.10 hours, and ebb strength increased or decreased by 6.21 hours (one-half of tidal cycle). Before taking the average, the four phases are made comparable by the addition or rejection of such multiples of 12.42 hours as may be necessary. The current hour is usually expressed in solar time, but if lunar time is desired, the solar hour should be multiplied by the factor 0.966.

current line—A graduated line attached to a current pole formerly used in measuring the velocity of the current. The line was marked in such a manner that the speed of the current, expressed in knots and tenths, was indicated directly by the length of line carried out by the current pole in a specified interval of time. When marked for a 60-second run, the principal divisions for whole knots were spaced at 101.33 feet and the subdivisions for tenths of knots were spaced at 10.13 feet. The current line was also known as a log line.

current meter—An instrument for measuring the speed and direction or just the speed of a current. The measurements are Eulerian when the meter is fixed or moored at a specific location. Current meters can be mechanical, electric, electromagnetic, acoustic, or any combination thereof.

current pole—A pole used in observing the velocity of the current. The pole formerly used by the Coast and Geodetic Survey was about 3 inches in diameter and 15 feet long, and was weighted at one end to float upright with the top about 1 foot out of water. Shorter poles were used when necessary for shallow water. In use, the pole was attached to the current line but separated from the graduated portion by an ungraded section of approximately 100 feet, known as the stray line. As the pole was carried out from an observing vessel by the current, the amount of line passing from the vessel during a specific time interval indicated the speed of the current. The set was obtained from a relative bearing from the vessel to the pole. The bearing was then related to the ship's compass and converted to true. See pelorus.

current station—The geographic location at which current observations are conducted. Also, the facilities used to make current observations. These may include a buoy, ground tackle, current meters, recording mechanism, and radio transmitter. See control current station and subordinate current station (1).

cyclonic ring—A meander breaking off from the main oceanic current and spinning in a counter-clockwise direction in the northern hemisphere (clockwise in southern).

D

data collection platform (DCP)—A microprocessor-based system that collects data from sensors, processes the data, stores the data in random access memory (RAM), and provides communication links for the retrieval or transmission of the data.

datum (vertical)—For marine applications, a base elevation used as a reference from which to reckon heights or depths. It is called a tidal datum when defined in terms of a certain phase of the tide. Tidal datums are local datums and should not be extended into areas which have differing hydrographic characteristics without substantiating measurements. In order that they may be recovered when needed, such datums are referenced to fixed points known as bench marks. See chart datum.

datum of tabulation—A permanent base elevation at a tide station to which all water level measurements are referred. The datum is unique to each station and is established at a lower elevation than the water is ever expected to reach. It is referenced to the primary bench mark at the station and is held constant regardless of changes to the water level gauge or tide staff. The datum of tabulation is most often at the zero of the first tide staff installed.

Davidson Current—A North Pacific Ocean counter-current setting northward between the California Current and the coasts of California, Oregon, and Washington during the winter months.

day—The period of rotation of the Earth. There are several kinds of days depending on whether the Sun, Moon, or other object or location is used as the reference for the rotation. See constituent day, lunar day, sidereal day, and solar day.

daylight saving time—A time used during the summer months, in some localities, in which clocks are advanced 1 hour from the usual standard time.

decibar—The practical unit for pressure in the ocean, equal to 10 centibars, and is the approximate pressure produced by each meter of overlying water

declination—Angular distance north or south of the celestial equator, taken as positive when north of the equator and negative when south. The Sun passes through its declinational cycle once a year, reaching its maximum north declination of approximately 23-½° about June 21 and its maximum south declination of approximately 23-½° about December 21. The Moon has an average declinational cycle of 27-½ days which is called a tropical month. Tides or tidal currents occurring near the times of maximum north or south declination of the Moon are called tropic tides or tropic currents, and those occurring when the Moon is over the Equator are called equatorial tides or equatorial currents. The maximum declination reached by the Moon in successive months depends upon the longitude of the Moon's node, and varies from 28-½° when the longitude of the ascending node is 0°, to 18-½° when the longitude of the node is 180° . The node cycle, or time required for the node to complete a circuit of 360° of longitude, is approximately 18.6 years. See epoch (2).

declinational inequality—Same as diurnal inequality.

declinational reduction—A processing of observed high and low waters or flood and ebb tidal currents to obtain quantities depending upon changes in the declination of the Moon; such as tropic ranges or speeds, height or speed inequalities, and tropic intervals.

density, in situ ($\rho_{s,t,p}$)—Mass per unit volume. The reciprocal of specific volume. In oceanography, the density of sea water, when expressed in gm/cm^3, is numerically equivalent to specific gravity and is a function of salinity, temperature, and pressure. See specific volume anomaly, thermosteric anomaly, sigma-t, and sigma-zero.

deviation (of compass)—The deflection of the needle of a magnetic compass due to masses of magnetic metal within a ship on which the compass is located. This deflection varies with different headings of the ship. The deviation is called easterly and marked plus if the deflection is to the right of magnetic north, and is called westerly and marked minus if it is to the left of magnetic north. A deviation table is a tabular arrangement showing the amount of deviation for different headings of the ship. Each compass requires a separate deviation table.

digital tide (water level) gauge—See automatic tide (water level) gauge.

direct method—A tidal datum computation method. Datums are determined directly by comparison with an appropriate control, for the available part of the tidal cycle. It is usually used only when a full range of tidal values are not available. For example: Direct Mean High Water, when low waters are not recorded.

direction of current—Same as set.

direction of wind—Direction from which the wind is blowing.

diurnal—Having a period or cycle of approximately one tidal day. Thus, the tide is said to be diurnal when only one high water and one low water occur during a tidal day, and the tidal current is said to be diurnal when there is a single flood and a single ebb period of a reversing current in the tidal day. A rotary current is diurnal if it changes its direction through all points of the compass once each tidal day. A diurnal constituent is one which has a single period in the constituent day. The symbol for such a constituent is the subscript 1. See stationary wave theory and type of tide.

diurnal inequality—The difference in height of the two high waters or of the two low waters of each tidal day; also, the difference in speed between the two flood tidal currents or the two ebb currents of each tidal day. The difference changes with the declination of the Moon and, to a lesser extent, with the declination of the Sun. In general, the inequality tends to increase with increasing declination, either north or south, and to diminish as the Moon approaches the Equator. Mean diurnal high water inequality (DHQ) is one-half the average difference between the two high waters of each tidal day observed over the National Tidal Datum Epoch. It is obtained by subtracting the mean of all the high waters from the mean of the higher high waters. Mean diurnal low water inequality (DLQ) is one-half the average difference between the two low waters of each tidal day observed over the National Tidal Datum Epoch. It is obtained by subtracting the mean of the lower low waters from the mean of all the low waters. Tropic high water inequality (HWQ) is the average difference between the two high waters of each tidal day at the times of tropic tides. Tropic low water inequality (LWQ) is the average difference between the two low waters of each tidal day at the times of tropic tides. Mean and tropic inequalities, as defined above, are applicable only when the type of tide is either semidiurnal or mixed. Diurnal inequality is sometimes called declinational inequality.

diurnal range—Same as great diurnal range.

diurnal tide level—A tidal datum midway between mean higher high water and mean lower low water.

double ebb—An ebb tidal current having two maxima of speed separated by a smaller ebb speed.

double flood—A flood tidal current having two maxima of speed separated by a smaller flood speed.

double tide—A double-headed tide, that is, a high water consisting of two maxima of nearly the same height separated by a relatively small depression, or a low water consisting of two minima separated by a relatively small elevation. Sometimes called an agger. See gulder.

drift (of current)—The speed of the current.

drift current—Same as wind drift.

duration of flood and duration of ebb—Duration of flood is the interval of time in which a tidal current is flooding, and duration of ebb is the interval in which it is ebbing, these intervals being reckoned from the middle of the intervening slack waters or minimum currents. Together they cover, on an average, a period of 12.42 hours for a semidiurnal tidal current or a period of 24.84 hours for a diurnal current. In a normal semidiurnal tidal current, the duration of flood and duration of ebb each will be approximately equal to 6.21 hours, but the times may be modified greatly by the presence of nontidal flow. In a river the duration of ebb is usually longer than the duration of flood because of fresh water discharge, especially during spring months when snow and ice melt are predominant influences.

duration of rise and duration of fall—Duration of rise is the interval from low water to high water, and duration of fall is the interval from high water to low water. Together they cover, on an average, a period of 12.42 hours for a semidiurnal tide or a period of 24.84 hours for a diurnal tide. In a normal semidiurnal tide, duration of rise and duration of fall each will be approximately equal to 6.21 hours, but in shallow waters and in rivers there is a tendency for a decrease in duration of rise and a corresponding increase in duration of fall.

dynamic decimeter—See geopotential as preferred term.

dynamic depth (height)—See geopotential difference as preferred term.

dynamic depth (height) anomaly—See geopotential anomaly as preferred term.

dynamic meter (D)—The former practical unit for geopotential difference (dynamic depth), equal to 10 geopotentials (dynamic decimeters). See geopotential (dynamic depth) anomaly.

dynamic topography—See geopotential topography as preferred term.

E

eagre (eager)—Same as tidal bore.

earth tide—Periodic movement of the Earth's crust caused by gravitational interactions between the Sun, Moon, and Earth.

East Africa Coast Current—Same as Somali Current.

East Australian Current—A South Pacific Ocean current setting southward along the east coast of Australia.

East Greenland Current—A North Atlantic Ocean current setting southward and then southwestward along the east coast of Greenland.

ebb axis—Average set of the current at ebb strength.

ebb current (ebb)—The movement of a tidal current away from shore or down a tidal river or estuary. In the mixed type of reversing tidal current, the terms greater ebb and lesser ebb are applied respectively to ebb tidal currents of greater and lesser speed each day. The terms maximum ebb and minimum ebb are applied to the maximum and minimum speeds of a current running continuously ebb, the speed alternately increasing and decreasing without coming to a slack or reversing. The expression maximum ebb is also applicable to any ebb current at the time of greatest speed. See ebb strength.

ebb interval—The interval between the transit of the Moon over the meridian of a place and the time of the following ebb strength.

ebb strength (strength of ebb)—Phase of the ebb tidal current at the time of maximum speed. Also, the speed at this time. See strength of current.

eccentricity of orbit—Ratio of the distance from the center to the focus of an elliptical orbit to the length of the semimajor axis. The eccentricity of orbit = $\sqrt{1 - (B / A)^2}$: where A and B are respectively the semimajor and semiminor axes of the orbit.

ecliptic—The intersection of the plane of the Earth's orbit with the celestial sphere.

eddy—A quasi-circular movement of water whose area is relatively small in comparison to the current with which it is associated.

edge waves—Waves moving between zones of high and low breakers along the shoreline. Edge waves contribute to changes in water level along the shoreface which helps to control the spacing of rip currents. See longshore current and rip current.

Ekman spiral—A logarithmic spiral (when projected on a horizontal plane) formed by the heads of current velocity vectors at increasing depths. The current vectors become progressively smaller with depth. They spiral to the right (looking in the direction of flow) in the Northern Hemisphere and to the left in the Southern with increasing depth. Theoretically, in deep water, the surface current vector sets 45° and the total mass transport sets 90° from the direction toward which the wind is blowing. Flow opposite to the surface current occurs at the so-called "depth of frictional resistance". The phenomenon occurs in wind drift currents in which only the Coriolis and frictional forces are significant. Named for Vagn Walfrid Ekman who, assuming a constant eddy viscosity, steady wind stress, and unlimited water depth and extent, derived the effect in 1905.

electric tape gauge—A gauge consisting of a graduated Monel metal tape on a metal reel (with supporting frame), voltmeter, and battery. Heights can be measured directly by unreeling the tape into its stilling well. When contact is made with the water's surface, the circuit is completed and the voltmeter needle moves. At that moment the length of tape is read against an index mark, the mark having a known elevation relative to the bench marks.

elimination—One of the final processes in the harmonic analysis of tides in which preliminary values for the harmonic constants of a number of constituents are cleared of the residual effects of each other.

epoch—(1) Also known as phase lag. Angular retardation of the maximum of a constituent of the observed tide (or tidal current) behind the corresponding maximum of the same constituent of the theoretical equilibrium tide. It may also be defined as the phase difference between a tidal constituent and its equilibrium argument. As referred to the local equilibrium argument, its symbol is κ. When referred to the corresponding Greenwich equilibrium argument, it is called the Greenwich epoch and is represented by G. A Greenwich epoch that has been modified to adjust to a particular time meridian for convenience in the prediction of tides is represented by g or by κ'. The relations between these epochs may be expressed by the following formula:

$G = \kappa + pL$

$g = \kappa' = G - aS / 15$

in which L is the longitude of the place and S is the longitude of the time meridian, these being taken as positive for west longitude and negative for east longitude; p is the number of constituent periods in the constituent day and is equal to 0 for all long-period constituents, 1 for diurnal constituents, 2 for semidiurnal constituents, and so forth; and a is the hourly speed of the constituent, all angular measurements being expressed in degrees. (2) As used in tidal datum determination, it is a 19-year cycle over which tidal height observations are meaned in order to establish the various datums. As there are periodic and apparent secular trends in sea level, a specific 19-year cycle (the National Tidal Datum Epoch) is selected so that all tidal datum determinations throughout the United States, its territories, Commonwealth of Puerto Rico, and Trust Territory of the Pacific Islands, will have a common reference. See National Tidal Datum Epoch.

equation of time— Difference between mean and apparent time. From the beginning of the year until near the middle of April, mean time is ahead of apparent time, the difference reaching a maximum of about 15 minutes near the middle of February. From the middle of April to the middle of June, mean time is behind apparent time but the difference is less than 5 minutes. From the middle of June to the first part of September, mean time is again ahead of apparent time with maximum difference less than 7 minutes. From the first of September until the later part of December, mean time is again behind apparent time, the difference reaching a maximum of nearly 17 minutes in the early part of November. The equation of time for each day in the year is given in the American Ephemeris and Nautical Almanac.

Equatorial Countercurrent—A current setting eastward between the North and South Equatorial Currents of the Atlantic, Pacific, and Indian (in northern winter) Oceans. In the Atlantic and Pacific, its axis lies about latitude 7° north and in the Indian, about 7° south.

equatorial tidal currents—Tidal currents occurring semimonthly as a result of the Moon being over the Equator. At these times the tendency of the Moon to produce a diurnal inequality in the tidal current is at a minimum.

equatorial tides—Tides occurring semimonthly as a result of the Moon being over the Equator. At these times the tendency of the Moon to produce a diurnal inequality in the tide is at a minimum.

Equatorial Undercurrent—A subsurface current setting eastward along the Equator in the Pacific, Atlantic, and Indian Oceans. In the Pacific, its core of maximum velocity lies at a depth of about 100 meters within the South Equatorial Current.

equilibrium argument—The theoretical phase of a constituent of the equilibrium tide. It is usually represented by the expression (V + u), in which V is a uniformly changing angular quantity involving multiples of the hour angle of the mean Sun, the mean longitudes of the Moon and Sun, and the mean longitude of lunar or solar perigee; and u is a slowly changing angle depending upon the longitude of the Moon's node. When pertaining to an initial instant of time, such as the beginning of a series of observations, it is expressed by (V_o+ u).

equilibrium theory—A model under which it is assumed that the waters covering the face of the Earth instantly respond to the tide-producing forces of the Moon and Sun to form a surface of equilibrium under the action of these forces. The model disregards friction, inertia, and the irregular distribution of the land masses of the Earth. The theoretical tide formed under these conditions is known as the equilibrium tide.

equilibrium tide—Hypothetical tide due to the tide producing forces under the equilibrium theory. Also known as gravitational tide.

equinoctial—The celestial equator.

equinoctial tides—Tides occurring near the times of the equinoxes.

equinoxes—The two points in the celestial sphere where the celestial equator intersects the ecliptic; also, the times when the Sun crosses the equator at these points. The vernal equinox is the point where the Sun crosses the Equator from south to north and it occurs about March 21. Celestial longitude is reckoned eastward from the vernal equinox. The autumnal equinox is the point where the Sun crosses the Equator from north to south and it occurs about September 23.

equipotential surface—Same as geopotential surface.

establishment of the port—Also known as high water, full and change (HWF&C). Average high water interval on days of the new and full Moon. This interval is also sometimes called the common or vulgar establishment to distinguish it from the corrected establishment, the latter being the mean of all the high water intervals. The latter is usually 10 to 15 minutes less than the common establishment.

estuary—An embayment of the coast in which fresh river water entering at its head mixes with the relatively saline ocean water. When tidal action is the dominant mixing agent it is usually termed a tidal estuary. Also, the lower reaches and mouth of a river emptying directly into the sea where tidal mixing takes place. The latter is sometimes called a river estuary.

Eulerian measurement—Observation of a current with a device fixed relative to the flow.

eustatic sea level rate—The worldwide change of sea level elevation with time. The changes are due to such causes as glacial melting or formation, thermal expansion or contraction of sea water, etc.

evection—A perturbation of the Moon depending upon the alternate increase and decrease of the eccentricity of its orbit, which is always a maximum when the Sun is passing the Moon's line of apsides and a minimum when the Sun is at right angles to it. The principal constituents in the tide resulting from the evectional inequality are ν_2, λ_2, and ρ_1.

extreme high water—The highest elevation reached by the sea as recorded by a water level gauge during a given period. The National Ocean Service routinely documents monthly and yearly extreme high waters for its control stations.

extreme low water—The lowest elevation reached by the sea as recorded by a water level gauge during a given period. The National Ocean Service routinely documents monthly and yearly extreme low water for its control stations.

F

Falkland Current—A South Atlantic Ocean current setting northeastward along the east coast of Argentina.

first reduction—A method of determining high and low water heights, time intervals, and ranges from an arithmetic mean without adjustment to a long-term series through comparison of simultaneous observations.

float well—A stilling well in which the float of a float-actuated water level gauge operates. See stilling well.

flood axis—The average set of the tidal current at strength of flood.

flood current (flood)—The movement of a tidal current toward the shore or up a tidal river or estuary. In the mixed type of reversing current, the terms greater flood and lesser flood are applied respectively to the two flood currents of greater and lesser speed of each day. The expression maximum flood is applicable to any flood current at the time of greatest speed. See flood strength.

flood interval—The interval between the transit of the Moon over the meridian of a place and the time of the following flood strength.

flood strength (strength of flood)—Phase of the flood tidal current at the time of maximum speed. Also, the speed at this time. See strength of current.

Florida Current—A North Atlantic Ocean current setting northward along the south-east coast of the United States. A segment of the Gulf Stream System, the Florida Current extends from the Straits of Florida to the region off Cape Hatteras.

flow—The British equivalent of the United States total current. Flow is the combination of tidal stream and current.

flushing time—The time required to remove or reduce (to a permissible concentration) any dissolved or suspended contaminant in an estuary or harbor.

forced wave—A wave generated and maintained by a continuous force.

fortnight—The time elasped between the new and full moons. Half a synodical month or 14.765,294 days. See synodical month.

Fourier series—A series proposed by the French mathematician Fourier about the year 1807. The series involves the sines and cosines of whole multiples of a varying angle and is usually written in the following form:

$$y = A_\circ + A_1 \sin x + A_2 \sin 2x + A_3 \sin 3x + \ldots B_1 \cos x + B_2 \cos 2x + B_3 \cos 3x + \ldots$$

By taking a sufficient number of terms the series may be assumed to represent any periodic function of x.

free wave—A wave that continues to exist after the generating force has ceased to act. See gravity wave.

G

gage—See tide (water level) gauge.

Galofaro—A whirlpool in the Strait of Messina; at one time called Charybdis.

gas purged pressure gauge—A type of water level gauge in which gas, usually nitrogen, is emitted from a submerged orifice at a constant rate. Fluctuations in hydrostatic pressure due to changes in water level modify the recorded emission rate. Same as bubbler tide (water level) gauge.

gauge—See tide (water level) gauge.

geodetic datum—See National Geodetic Vertical Datum of 1929 (NGVD 1929) and North American Vertical Datum of 1988 (NAVD 1988).

geopotential—The unit of geopotential difference, equal to the gravity potential of 1 meter squared per second squared, m^2 / s^2, or 1 joule per kilogram, J / kg.

geopotential anomaly (ΔD)—The excess in geopotential difference over the standard geopotential difference [at a standard specific volume at 35 parts per thousand (‰) and 0 degrees C] between isobaric surfaces. See geopotential and geopotential topography.

$$\Delta D = \int_{P_1}^{P_2} \delta dp$$

where p is the pressure and δ, the specific volume anomaly. P_1 and P_2 are the pressures at the two surfaces.

geopotential difference—The work per unit mass gained or required in moving a unit mass vertically from one geopotential surface to another. See geopotential, geopotential anomaly, and geopotential topography.

geopotential (equipotential) surface—A surface that is everywhere normal to the acceleration of gravity.

geopotential topography—The topography of an equiscalar (usually isobaric) surface in terms of geopotential difference. As depicted on maps, isopleths are formed by the intersection of the isobaric surface with a series of geopotential surfaces. Thus, the field of isopleths represents variations in the geopotential anomaly of the isobaric surface above a chosen reference isobaric surface (such as a level of no motion).

geostrophic flow—A solution of the relative hydrodynamic equations of motion in which it is assumed that the horizontal component of the Coriolis force is balanced by the horizontal component of the pressure gradient force.

gradient flow—A solution of the relative hydrodynamic equations of motion in which only the horizontal Coriolis, pressure gradient, and centrifugal forces are considered.

gravitational tide—Same as equilibrium tide.

gravity wave—A wave for which the restoring force is gravity.

great diurnal range (Gt)—The difference in height between mean higher high water and mean lower low water. The expression may also be used in its contracted form, diurnal range.

great tropic range (Gc)—The difference in height between tropic higher high water and tropic lower low water. The expression may also be used in its contracted form, tropic range.

Greenwich argument—Equilibrium argument computed for the meridian of Greenwich.

Greenwich epoch—See epoch (1).

Greenwich interval—An interval referred to the transit of the Moon over the meridian of Greenwich, as distinguished from the local interval which is referred to the Moon's transit over the local meridian. The relation in hours between Greenwich and local intervals may be expressed by the formula:

Greenwich interval = local interval + 0.069L

where L is the west longitude of the local meridian in degrees. For east longitude, L is to be considered negative.

Gregorian calendar—The modern calendar in which every year divisible by 4 (excepting century years) and every century year divisible by 400 are bissextile (or leap) years with 366 days. All other years are common years with 365 days. The average length of this year is, therefore, 365.242,5 days which agrees very closely with the length of the tropical year (the period of changes in seasons). The Gregorian calendar was introduced by Pope Gregory in 1582, and immediately adopted by the Catholic countries in place of the Julian calendar previously in use. In making the change it was ordered that the day following October 4, 1582, of the Julian calendar be designated October 15, 1582, of the Gregorian calendar; the 10 days being dropped in order that the vernal equinox would fall on March 21. The Gregorian calendar was not adopted by England until 1752, but is now in general use throughout the world.

Guiana Current—An Atlantic Ocean current setting northwestward along the north-east coast of South America.

Guinea Current—An Atlantic Ocean current setting eastward along the west central coast of Africa. A continuation of the Equatorial Counter Current of the Atlantic Ocean.

gulder—Local name given to the double low water occurring on the south coast of England. See double tide.

Gulf Coast Low Water Datum (GCLWD)—A tidal datum. Used as chart datum from November 14, 1977, to November 27, 1980, for the coastal waters of the Gulf coast of the United States. GCLWD is defined as mean lower low water when the type of tide is mixed and mean low water (now mean lower low water) when the type of tide is diurnal. See National Tidal Datum Convention of 1980.

Gulf Coast Low Water Datum line—The line on a chart or map which represents the intersection of the land with the water surface at the elevation of Gulf Coast Low Water Datum.

Gulf Stream—A North Atlantic Ocean current setting northeastward off the east coast of the United States. A segment of the Gulf Stream System, the Gulf Stream extends from the region off Cape Hatteras to an area southeast of the Grand Banks at about latitude 40° north, longitude 50° west. It continues the flow of the Florida Current to the North Atlantic Current.

Gulf Stream System—The continuous current system composed of the Florida Current, Gulf Stream, and North Atlantic Current.

H

h—Rate of change (as of January 1, 1900) in mean longitude of the Sun.
h = 0.041,068,64° per solar hour.

half-tide level—Same as mean tide level.

halocline—A layer in which the salinity changes significantly (relative to the layers above and below) with depth.

harmonic analysis—The mathematical process by which the observed tide or tidal current at any place is separated into basic harmonic constituents.

harmonic analyzer—A machine designed for the resolution of a periodic curve into its harmonic constituents. Now performed by electronic digital computer.

harmonic constants—The amplitudes and epochs of the harmonic constituents of the tide or tidal current at any place.

harmonic constituent—See constituent.

harmonic function—In its simplest form, a quantity that varies as the cosine of an angle that increases uniformly with time. It may be expressed by the formula:

$y = A \cos at$

in which y is a function of time (t), A is a constant coefficient, and a is the rate of change in the angle at.

harmonic prediction—Method of predicting tides and tidal currents by combining the harmonic constituents into a single tide curve. The work is usually performed by electronic digital computer.

harmonic reduction—Same as harmonic analysis.

harmonic tide plane—Same as Indian spring low water.

head—The difference in water level at either end of a strait, channel, inlet, etc.

head of tide—The inland or upstream limit of water affected by the tide. For practical application in the tabulation for computation of tidal datums, head of tide is the inland or upstream point where the mean range becomes less than 0.2 foot. Tidal datums (except for mean water level) are not computed beyond head of tide.

high tide—Same as high water.

high water (HW)—The maximum height reached by a rising tide. The high water is due to the periodic tidal forces and the effects of meteorological, hydrologic, and/or oceanographic conditions. For tidal datum computational purposes, the maximum height is not considered a high water unless it contains a tidal high water.

high water, full and change (HWF&C)—Same as establishment of the port.

high water inequality—See diurnal inequality.

high water interval (HWI)—See lunitidal interval.

high water line—The intersection of the land with the water surface at an elevation of high water.

high water mark—A line or mark left upon tide flats, beach, or along shore objects indicating the elevation of the intrusion of high water. The mark may be a line of oil or scum on along shore objects, or a more or less continuous deposit of fine shell or debris on the foreshore or berm. This mark is physical evidence of the general height reached by wave run up at recent high waters. It should not be confused with the mean high water line or mean higher high water line.

higher high water (HHW)—The highest of the high waters (or single high water) of any specified tidal day due to the declinational effects of the Moon and Sun.

higher low water (HLW)—The highest of the low waters of any specified tidal day due to the declinational effects of the Moon and Sun.

Humboldt Current—Same as Peru Current.

hydraulic current—A current in a channel caused by a difference in the surface elevation at the two ends. Such a current may be expected in a strait connecting two bodies of water in which the tides differ in time or range. The current in the East River, New York, connecting Long Island Sound and New York Harbor, is an example.

hydrographic datum—A datum used for referencing depths of water and the heights of predicted tides or water level observations. Same as chart datum. See datum.

I

incremental shaft encoder—A component of a water level gauge for converting length to a shaft angle on a rotating disk. The position of the rotating disk is determined by single or dual optical or magnetic sensors to provide an electrical output. No electro-mechanical components or gears are used, so extremely low torque is required to move the float wheel, wire, and float mechanism.

Indian spring low water—A datum originated by Professor G. H. Darwin when investigating the tides of India. It is an elevation depressed below mean sea level by an amount equal to the sum of the amplitudes of he harmonic constituents M_2, S_2, K_1, and O_1.

Indian tide plane—Same as Indian spring low water.

inequality—A systematic departure from the mean value of a tidal quantity. See diurnal inequality, parallax inequality, and phase inequality.

inertial flow—A solution of the relative hydrodynamic equations of motion in which only the horizontal component of the Coriolis and centrifugal forces are balanced. This anticyclonic flow results from a sudden application and release of a driving force which then allows the system to continue on under its own momentum without further interference. The period of rotation is $2\pi / 2\Omega \sin ø$, where $\Omega = 0.729,211 \times 10^{-4}$ radians s^{-1} and ø = latitude.

internal tide—A tidal wave propagating along a sharp density discontinuity, such as a thermocline, or in an area of gradually changing (vertically) density.

International Great Lakes Datum (1985) [IGLD 1985]—Mean water level at Rimouski/Pointe-au-Pere, Quebec, on the Gulf of St. Lawrence over the period 1970 through 1988, from which geopotential elevations (geopotential differences) throughout the Great Lakes region are measured. The term is often used to mean the entire system of geopotential elevations rather than just the referenced water level. See low water datum (1).

International Hydrographic Organization (formerly Bureau)—An institution consisting of representatives of a number of nations organized for the purpose of coordinating the hydrographic work of the participating governments. It had its origin in the International Hydrographic Conference in London in 1919. It has permanent headquarters in the Principality of Monaco and is supported by funds provided by the member nations. Its principal publications include the Hydrographic Review and special publications on technical subjects.

intertidal zone—(technical definition) The zone between the mean higher high water and mean lower low water lines.

interval—See lunitidal interval and lunicurrent interval.

inverse barometer effect—The inverse response of sea level to changes in atmospheric pressure. A static reduction of 1.005 mb in atmospheric pressure will cause a stationary rise of 1 cm in sea level.

Irminger Current—A North Atlantic Ocean current setting westward off the south-west coast of Iceland.

isanostere—An isopleth of either specific volume anomaly or thermosteric anomaly.

isobar—An isopleth of pressure.

isobaric surface—A surface of constant or uniform pressure.

isohaline—An isopleth of salinity. Constant or uniform in salinity.

isopleth—A line of constant or uniform value of a given quantity. See isanostere, isobar, isohaline, isopycnic, and isotherm.

isopycnic—An isopleth of density. Constant or uniform in density.

isotherm—An isopleth of temperature.

J

J_1—Smaller lunar elliptic diurnal constituent. This constituent, with M_1, modulates the amplitudes of the declinational K_1, for the effect of the Moon's elliptical orbit. Speed = T + s + h - p = 15.585,443,3° per solar hour.

Japan Current—Same as Kuroshio.

Julian calendar—A calendar introduced by Julius Caesar in the year 45 B.C., and slightly modified by Augustus a few years later. This calendar provided that the common year should consist of 365 days and that every fourth year, now known as a bissextile or leap year, should contain 366 days, making the average length of the year 365.25 days. It differs from the modern or Gregorian calendar in having every fourth year a leap year, while in the modern calendar century years not divisible by 400 are common years. See Gregorian calendar.

Julian date—Technique for the identification of successive days of the year when monthly notation is not desired. This is especially applicable in computer data processing and acquisition where indexing is necessary.

K

K_1—Lunisolar diurnal constituent. This constituent, with O_1, expresses the effect of the Moon's declination. They account for diurnal inequality and, at extremes, diurnal tides. With P_1, it expresses the effect of the Sun's declination.
Speed = T + h = 15.041,068,6° per solar hour.

K_2—Lunisolar semi diurnal constituent. This constituent modulates the amplitude and frequency of M_2 and S_2 for the declinational effect of the Moon and Sun, respectively.
Speed = 2T + 2h = 30.082,137,3° per solar hour.

kappa (κ)—Name of Greek letter used as the symbol for a constituent phase lag or epoch when referred to the local equilibrium argument and frequently taken to mean the same as local epoch. See epoch (1).

kappa prime (κ')—Name of Greek letter (with prime mark) used as the symbol for a constituent phase lag or epoch when the Greenwich equilibrium argument (G) has been modified to a particular time meridian. Same as g. See kappa (κ) and epoch (1).

knot—A speed unit of 1 international nautical mile (1,852.0 meters or 6,076.115,49 international feet) per hour.

Kuroshio—"Black Stream" in Japanese. A North Pacific Ocean current setting northeastward off the east coast of Taiwan and Japan from Taiwan to about latitude 35° north.

Kuroshio Extension—A North Pacific Ocean current setting eastward from about longitude 145° east to about 160° east. It continues the flow of the Kuroshio to the North Pacific Current.

Kuroshio System—The current system composed of the Kuroshio, Tsushima Current, Kuroshio Extension, and North Pacific Current.

L

L_2—Smaller lunar elliptic semi diurnal constituent. This constituent, with N_2, modulates the amplitude and frequency of M_2 for the effect of variation in the Moon's orbital speed due to its elliptical orbit.
Speed = 2T − s + 2h − p = 29.528,478,9° per solar hour.

Labrador Current—A North Atlantic Ocean current setting southeastward along the east coasts of Baffin Island, Labrador, and Newfoundland.

lagging of tide—The periodic retardation in the time of occurrence of high and low water due to changes in the relative positions of the Moon and Sun.

Lagrangian measurement—Observation of a current with a device moving with the current.

lambda (λ_2)—Smaller lunar evectional constituent. This constituent, with ν_2, μ_2, and (S_2), modulates the amplitude and frequency of M_2 for the effects of variation in solar attraction of the Moon. This attraction results in a slight pear-shaped lunar ellipse and a difference in lunar orbital speed between motion toward and away from the Sun. Although (S_2) has the same speed as S_2, its amplitude is extremely small.
Speed = 2T − s + p = 29.455,625,3° per solar hour.

latitude—The angular distance between a terrestrial position and the equator measured northward or southward from the equator along a meridian of longitude.

leap year—A calendar year containing 366 days. According to the present Gregorian calendar, all years with the date-number divisible by 4 are leap years, except century years. The latter are leap years when the date-number is divisible by 400.

level of no motion—A level (or layer) at which it is assumed that an isobaric surface coincides with a geopotential surface. A level (or layer) at which there is no horizontal pressure gradient force.

level surface—See geopotential surface as preferred term.

littoral current—A current in the littoral zone such as a long shore or rip current.

littoral zone—In coastal engineering, the area from the shoreline to just beyond the breaker zone. In biological oceanography, it is that part of the benthic division extending from the high water line out to a depth of about 200 meters. The littoral system is divided into a eulittoral and sublittoral zone, separated at a depth of about 50 meters. Also, frequently used interchangeably with intertidal zone.

local epoch—See kappa (κ) and epoch (1).

local time—Time in which noon is defined by the transit of the Sun over the local meridian as distinguished from standard time which is based upon the transit of the Sun over a standard meridian. Local time may be either mean or apparent, according to whether reference is to the mean or actual Sun. Local time was in general use in the United States until 1883, when standard time was adopted. The use of local time in other parts of the world has also been practically abandoned in favor of the more convenient standard time.

log line—A graduated line used to measure the speed of a vessel through the water or to measure the velocity of the current from a vessel at anchor. See current line.

long period constituent—A tidal or tidal current constituent with a period that is independent of the rotation of the Earth but which depends upon the orbital movement of the Moon or the Earth. The principal lunar long period constituents have periods approximating a month and half a month, and the principal solar long period constituents have periods approximating a year and half a year.

long period waves (long waves)—Forced or free waves whose lengths are much longer than the water depth. See tidal wave and tsunami.

longitude—Angular distance along a great circle of reference reckoned from an accepted origin to the projection of any point on that circle. Longitude on the Earth's surface is measured on the Equator east and west of the meridian of Greenwich and may be expressed either in degrees or in hours, the hour being taken as the equivalent of 15° of longitude. Celestial longitude is measured in the ecliptic eastward from the vernal equinox. The mean longitude of a celestial body moving in an orbit is the longitude that would be attained by a point moving uniformly in the circle of reference at the same average angular velocity as that of the body, with the initial position of the point so taken that its longitude would be the same as that of the body at a certain specified position in its orbit. With a common initial point, the mean longitude of a body will be the same in whatever circle it may be reckoned.

longshore current—A current paralleling the shore largely within the surf zone. It is caused by the excess water brought to the zone by the small net mass transport of wind waves. Long shore currents feed into rip currents. See progressive wave.

loop of stationary wave—That portion of the oscillating area where the vertical movement is greatest.

Loop Current—A current setting clockwise in the Gulf of Mexico. It enters through the Yucatan Channel from the Caribbean Sea and leaves through the Straits of Florida.

low tide—Same as low water.

low water (LW)—The minimum height reached by a falling tide. The low water is due to the periodic tidal forces and the effects of meteorological, hydrologic, and/or oceanographic conditions. For tidal datum computational purposes, the minimum height is not considered a low water unless it contains a tidal low water.

low water datum (LWD)—(1) The geopotential elevation (geopotential difference) for each of the Great Lakes and Lake St. Clair and the corresponding sloping surfaces of the St. Marys, St. Clair, Detroit, Niagara, and St. Lawrence Rivers to which are referred the depths shown on the navigational charts and the authorized depths for navigation improvement projects. Elevations of these planes are referred to IGLD 1985 and are Lake Superior—183.2 meters, Lakes Michigan and Huron—176.0 meters, Lake St. Clair—174.4 meters, Lake Erie—173.5 meters, and Lake Ontario—74.2 meters. (2) An approximation of mean low water that has been adopted as a standard reference for a limited area and is retained for an indefinite period regardless of the fact that it may differ slightly from a better determination of mean low water from a subsequent series of observations. Used primarily for river and harbor engineering purposes. Boston low water datum is an example.

low water equinoctial springs—Low water springs near the times of the equinoxes. Expressed in terms of the harmonic constants, it is an elevation depressed below mean sea level by an amount equal to the sum of the amplitudes of the constituents M_2, S_2, and K_2.

low water inequality—See diurnal inequality.

low water interval (LWI)—See lunitidal interval.

low water line—The intersection of the land with the water surface at an elevation of low water.

lower high water (LHW)—The lowest of the high waters of any specified tidal day due to the declinational effects of the Moon and Sun.

lower low water (LLW)—The lowest of the low waters (or single low water) of any specified tidal day due to the declinational effects of the Moon and Sun.

lower low water datum (LLWD)—An approximation of mean lower low water that has been adopted as a standard reference for a limited area and is retained for an indefinite period regardless of the fact that it may differ slightly from a better determination of mean lower low water from a subsequent series of observations. Used primarily for river and harbor engineering purposes. Columbia River lower low water datum is an example.

lowest astronomical tide—As defined by the International Hydrographic Organization, the lowest tide level that can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions.

lunar cycle—An ambiguous expression which has been applied to various cycles associated with the Moon's motion. See Callippic cycle, Metonic cycle, node cycle, and synodical month.

lunar day—The time of the rotation of the Earth with respect to the Moon, or the interval between two successive upper transits of the Moon over the meridian of a place. The mean lunar day is approximately 24.84 solar hours in length, or 1.035 times as great as the mean solar day.

lunar interval—The difference in time between the transit of the Moon over the meridian of Greenwich and a local meridian. The average value of this interval, expressed in hours, is 0.069 L, where L is the local longitude in degrees, positive for west longitude and negative for east. The lunar interval equals the difference between the local and Greenwich interval of a tide or current phase.

lunar month—Same as synodical month.

lunar nodes—The points where the plane of the Moon's orbit intersects the ecliptic. The point where the Moon crosses in going from south to north is called the ascending node and the point where the crossing is from north to south is called the descending node. References are usually made to the ascending node which, for brevity, may be called the node.

lunar tide—That part of the tide on the Earth due solely to the Moon as distinguished from that part due to the Sun.

lunar time—Time based upon the rotation of the Earth relative to the Moon. See lunar day.

lunation—Same as synodical month.

lunicurrent interval—The interval between the Moon's transit (upper or lower) over the local or Greenwich meridian and a specified phase of the tidal current following the transit. Examples are strength of flood interval and strength of ebb interval, which may be abbreviated to flood interval and ebb interval, respectively. The interval is described as local or Greenwich according to whether the reference is to the Moon's transit over the local or Greenwich meridian. When not otherwise specified, the reference is assumed to be local. For a and b markings, see lunitidal interval.

lunisolar tides—Harmonic tidal constituents K_1, and K_2, which are derived partly from the development of the lunar tide and partly from the solar tide, the constituent speeds being the same in both cases. Also, the lunisolar synodic fortnightly constituent MSf.

lunitidal interval—The interval between the Moon's transit (upper or lower) over the local or Greenwich meridian and the following high or low water. The average of all high water intervals for all phases of the Moon is known as mean high water lunitidal interval and is abbreviated to high water interval (HWI). Similarly, mean low water lunitidal interval is abbreviated to low water interval (LWI). The interval is described as local or Greenwich according to whether the reference is to the transit over the local or Greenwich meridian. When not otherwise specified, the reference is assumed to be local.
When there is considerable diurnal inequality in the tide, separate intervals may be obtained for the higher high waters, lower high waters, higher low waters, and lower low waters. These are designated respectively as higher high water interval (HHWI), lower high water interval (LHWI), higher low water interval (HLWI), and lower low water interval (LLWI). In such cases, and also when the tide is diurnal, it is necessary to distinguish between the upper and lower transit of the Moon with reference to its declination. Intervals referred to the Moon's upper transit at the time of its north declination or the lower transit at the time of south declination are marked a. Intervals referred to the Moon's lower transit at the time of its north declination or to the upper transit at the time of south declination are marked b.

M

M_1—Smaller lunar elliptic diurnal constituent. This constituent, with J_1, modulates the amplitude of the declinational K_1, for the effect of the Moon's elliptical orbit. A slightly slower constituent, designated (M_1), with Q_1, modulates the amplitude and frequency of the declinational O_1, for the same effect.
Speed = T – s + h + p = 14.496,693,9° per solar hour.

M_2—Principal lunar semidiurnal constituent. This constituent represents the rotation of the Earth with respect to the Moon.
Speed = 2T – 2s + 2h = 28.984,104,2° per solar hour.

M_3—Lunar terdiurnal constituent. A shallow water compound constituent. See shallow water constituent.
Speed = 3T – 3s + 3h = 43.476,156,3° per solar hour.

M_4, M_6, M_8—Shallow water overtides of the principal lunar constituent. See shallow water constituent.
Speed of M_4 = $2M_2$ = 4T – 4s + 4h = 57.968,208,4° per solar hour.

Speed of $M_6 = 3M_2 = 6T - 6s + 6h = 86.952,312,7°$ per solar hour.
Speed of $M_8 = 4M_2 = 8T - 8s + 8h = 115.936,416,9°$ per solar hour.

Maelstrom—Famous whirlpool off the coast of Norway in the Lofoten Islands between Moskenesoy and Mosken.

magnetic azimuth—Azimuth reckoned from the magnetic north or magnetic south. See magnetic direction.

magnetic declination—Same as variation.

magnetic direction—Direction as indicated by a magnetic compass after correction for deviation but without correction for variation.

marigram—A graphic record of the rise and fall of water level. The record is in the form of a curve in which time is generally represented on the abscissa and the height of the water level on the ordinate. See tide curve.

marine boundary—The mean lower low water line (MLLWL) when used as a boundary. Also, lines used as boundaries seaward of and measured from (or points thereon) the MLLWL. See coastal boundary.

mascaret—French for tidal bore.

mean current hour—Same as current hour.

mean diurnal tide level (MDTL)—A tidal datum. The arithmetic mean of mean higher high water and mean lower low water.

mean high water (MHW)—A tidal datum. The average of all the high water heights observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.

mean high water line (MHWL)—The line on a chart or map which represents the intersection of the land with the water surface at the elevation of mean high water. See shoreline.

mean higher high water (MHHW)—A tidal datum. The average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.

mean higher high water line (MHHWL)—The line on a chart or map which represents the intersection of the land with the water surface at the elevation of mean higher high water.

mean low water (MLW)—A tidal datum. The average of all the low water heights observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.

mean low water line (MLWL)—The line on a chart or map which represents the intersection of the land with the water surface at the elevation of mean low water.

mean low water springs (MLWS)—A tidal datum. Frequently abbreviated spring low water. The arithmetic mean of the low water heights occurring at the time of spring tides observed over the National Tidal Datum Epoch. It is usually derived by taking an elevation depressed below the half-tide level by an amount equal to one-half the spring range of tide, necessary corrections being applied to reduce the result to a mean value. This datum is used, to a considerable extent, for hydrographic work outside of the United States and is the level of reference for the Pacific approaches to the Panama Canal.

mean lower low water (MLLW)—A tidal datum. The average of the lower low water height of each tidal day observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.

mean lower low water line (MLLWL)—The line on a chart or map which represents the intersection of the land with the water surface at the elevation of mean lower low water.

mean range of tide (Mn)—The difference in height between mean high water and mean low water.

mean rise—The height of mean high water above the elevation of chart datum.

mean rise interval (MRI)—The average interval between the transit of the Moon and the middle of the period of the rise of the tide. It may be computed by adding half the duration of rise to the mean low water interval, subtracting the semidiurnal tidal period of 12.42 hours when greater than this amount. The mean rise interval may be either local or Greenwich according to whether it is referred to the local or Greenwich transit.

mean river level—A tidal datum. The average height of the surface of a tidal river at any point for all stages of the tide observed over the National Tidal Datum Epoch. It is usually determined from hourly height readings. In rivers subject to occasional freshets, the river level may undergo wide variations and, for practical purposes, certain months of the year may be excluded in the determination of the tidal datum. For charting purposes, tidal datums for rivers are usually based on observations during selected periods when the river is at or near a low water stage.

mean sea level (MSL)—A tidal datum. The arithmetic mean of hourly heights observed over the National Tidal Datum Epoch. Shorter series are specified in the name; e.g., monthly mean sea level and yearly mean sea level.

mean sun—A fictitious sun which is assumed to move in the celestial equator at a uniform speed corresponding to the average angular speed of the real Sun in the ecliptic, the mean sun being alternately in advance and behind the real Sun. It is used as a reference for reckoning mean time, noon of mean local time corresponding to the time of the transit of the mean sun over the local meridian. See equation of time and mean time.

mean tide level (MTL)—A tidal datum. The arithmetic mean of mean high water and mean low water. Same as half-tide level.

mean time—Time based upon the hour angle of the mean sun as distinguished from apparent time which is based upon the position of the real Sun. The difference between apparent and mean time is known as the equation of time.

mean water level (MWL)—A datum. The mean surface elevation as determined by averaging the heights of the water at equal intervals of time, usually hourly. Mean water level is used in areas of little or no range in tide.

mean water level line (MWLL)—The line on a chart or map which represents the intersection of the land with the water surface at the elevation of mean water level.

meteorological tides—Tidal constituents having their origin in the daily or seasonal variations in weather conditions which may occur with some degree of periodicity. The principal meteorological constituents recognized in the tides are Sa, Ssa, and S_1. See storm surge.

Metonic cycle—A period of almost 19 years or 235 lunations. Devised by Meton, an Athenian astronomer who lived in the fifth century B.C., for the purpose of obtaining a period in which new and full Moon would recur on the same day of the year. Taking the Julian year of 365.25 days and the synodical month as 29.530,588 days, we have the 19-year period of 6,939.75 days as compared with the 235 lunations of 6,939.69 days, a difference of only 0.06 day.

Mf—Lunar fortnightly constituent. This constituent expresses the effect of departure from a sinusoidal declinational motion.
Speed = 2s = 1.098,033,1° per solar hour.

midextreme tide—An elevation midway between extreme high water and extreme low water occurring in any locality.

mixed (current)—Type of tidal current characterized by a conspicuous diurnal inequality in the greater and lesser flood strengths and/or greater and lesser ebb strengths. See flood current and ebb current.

mixed (tide)—Type of tide characterized by a conspicuous diurnal inequality in the higher high and lower high waters and/or higher low and lower low waters. See type of tide.

Mm—Lunar monthly constituent. This constituent expresses the effect of irregularities in the Moon's rate of change of distance and speed in orbit.
Speed = s – p = 0.544,374,7° per solar hour.

modified epoch—See kappa prime (κ') and epoch (1).

modified-range ratio method—A tidal datum computation method. Generally used for the East Coast, Gulf Coast, and Caribbean Island stations. Values needed are mean tide level (MTL), mean diurnal tide level (DTL), mean range of tide (MN), and great diurnal range (GT) as determined by comparison with an appropriate control. From those, the following are computed:
MLW = MTL - (0.5*MN)
MHW = MLW + MN
MLLW = DTL - (0.5*GT)
MHHW = MLLW + GT

Monsoon Current (Southwest Monsoon Current)—An Indian Ocean current setting in a generally eastward to southeastward direction off India and Ceylon. It replaces the North Equatorial Current, reversed by wind stress of the south-west monsoons, in August and September.

month—The period of the revolution of the Moon around the Earth. The month is designated as siderial, tropical, anomalistic, nodical, or synodical according to whether the revolution is relative to a fixed star, vernal equinox, perigee, ascending node, or Sun. The calendar month is a rough approximation to the synodical month.

MSf—Lunisolar synodic fortnightly constituent.
Speed = 2s – 2h = 1.015,895,8° per solar hour.

mu (μ_2)—Variational constituent. See lambda.
Speed = 2T – 4s + 4h = 27.968,208,4° per solar hour.

multiple tide staff—A succession of tide staffs on a sloping shore so placed that the vertical graduations on the several staffs will form a continuous scale referred to the same datum.

N

N—Rate of change (as of January 1, 1900) in mean longitude of the Moon's node.
N = – 0.002,206,41° per solar hour.

N_2—Larger lunar elliptic semi diurnal constituent. See L_2
Speed = 2T – 3s + 2h + p = 28.439,729,5° per solar hour.

$2N_2$—Lunar elliptic semi diurnal second-order constituent.
Speed = 2T – 4s + 2h + 2p = 27.895,354,8° per solar hour.

National Geodetic Vertical Datum of 1929 [NGVD 1929]—A fixed reference adopted as a standard geodetic datum for elevations determined by leveling. The datum was derived for surveys from a general adjustment of the first-order leveling nets of both the United States and Canada. In the adjustment, mean sea level was held fixed as observed at 21 tide stations in the United States and 5 in Canada. The year indicates the time of the general adjustment. A synonym for Sea-level Datum of 1929. The geodetic datum is fixed and does not take into account the changing stands of sea level. Because there are many variables affecting sea level, and because the geodetic datum represents a best fit over a broad area, the relationship between the geodetic datum and local mean sea level is not consistent from one location to another in either time or space. For this reason, the National Geodetic Vertical Datum should not be confused with mean sea level. See North American Vertical Datum of 1988 (NAVD 1988).

National Spatial Reference System (NSRS)—A consistent national coordinate system that defines latitude, longitude, height, scale, gravity, and orientation throughout the nation, and how these values change with time. The NSRS is developed and maintained by the National

Geodetic Survey using advanced geodetic, photogrammetric, and remote sensing techniques.

National Tidal Datum Convention of 1980—Effective November 28, 1980, the Convention: (1) establishes one uniform, continuous tidal datum system for all marine waters of the United States, its territories, Commonwealth of Puerto Rico, and Trust Territory of the Pacific Islands, for the first time in history; (2) provides a tidal datum system independent of computations based on type of tide; (3) lowers chart datum from mean low water to mean lower low water along the Atlantic coast of the United States; (4) updates the National Tidal Datum Epoch from 1941 through 1959, to 1960 through 1978; (5) changes the name Gulf Coast Low Water Datum to mean lower low water; (6) introduces the tidal datum of mean higher high water in areas of predominantly diurnal tides; and (7) lowers mean high water in areas of predominantly diurnal tides. See chart datum.

National Tidal Datum Epoch—The specific 19-year period adopted by the National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values (e.g., mean lower low water, etc.) for tidal datums. It is necessary for standardization because of periodic and apparent secular trends in sea level. The present National Tidal Datum Epoch is 1960 through 1978. It is reviewed annually for possible revision and must be actively considered for revision every 25 years.

National Water Level Observation Network (NWLON)—The network of tide and water level stations operated by the National Ocean Service along the marine and Great Lakes coasts and islands of the United States.

The NWLON is composed of the primary and secondary control tide stations of the National Ocean Service. This Network provides the basic tidal datums for coastal and marine boundaries and for chart datum of the United States. Tide observations at a secondary control tide station or tertiary tide station are reduced to equivalent 19-year tidal datums through comparison of simultaneous observations with a primary control tide station. In addition to hydrography, nautical charting, and delineation of coastal and marine boundaries, the Network is used for coastal processes and tectonic studies, tsunami and storm surge warnings, and climate monitoring.

The National Water Level Observation Network also includes stations operated throughout the Great Lakes Basin. The network supports regulation, navigation and charting, river and harbor improvement, power generation, various scientific activities, and the adjustment for vertical movement of the Earth's crust in the Great Lakes Basin.

neap range—See neap tides.

neap tides or tidal currents—Tides of decreased range or tidal currents of decreased speed occurring semimonthly as the result of the Moon being in quadrature. The neap range (Np) of the tide is the average range occurring at the time of neap tides and is most conveniently computed from the harmonic constants. It is smaller than the mean range where the type of tide is either semidiurnal or mixed and is of no practical significance where the type of tide is predominantly diurnal. The average height of the high waters of the neap tide is called neap high water or high water neaps (MHWN) and the average height of the corresponding low waters is called neap low water or low water neaps (MLWN).

Next Generation Water Level Measurement System (NGWLMS)—A fully integrated system encompassing new technology sensors and recording equipment, multiple data transmission options, and an integrated data processing, analysis, and dissemination subsystem.

nodal line—A line in an oscillating body of water along which there is a minimum or zero rise and fall of the tide.

nodal point—The zero tide point in an amphidromic region.

node—See lunar nodes.

node cycle—Period of approximately 18.61 Julian years required for the regression of the Moon's nodes to complete a circuit of 360° of longitude. It is accompanied by a corresponding cycle of changing inclination of the Moon's orbit relative to the plane of the Earth's Equator, with resulting inequalities in the rise and fall of the tide and speed of the tidal current.

node factor (f)—A factor depending upon the longitude of the Moon's node which, when applied to the mean coefficient of a tidal constituent, will adapt the same to a particular year for which predictions are to be made.

nodical month—Average period of the revolution of the Moon around the Earth with respect to the Moon's ascending node. It is approximately 27.212,220 days in length.

nonharmonic constants—Tidal constants such as lunitidal intervals, ranges, and inequalities which may be derived directly from high and low water observations without regard to the harmonic constituents of the tide. Also applicable to tidal currents.

nontidal current—See current.

normal tide—A nontechnical term synonymous with tide; i.e., the rise and fall of the ocean due to the gravitational interactions of the Sun, Moon, and Earth alone. Use of this term is discouraged.

North American Vertical Datum of 1988 [NAVD 1988]—A fixed reference for elevations determined by geodetic leveling. The datum was derived from a general adjustment of the first-order terrestrial leveling nets of the United States, Canada, and Mexico. In the adjustment, only the height of the primary tidal bench mark, referenced to the International Great Lakes Datum of 1985 (IGLD 1985) local mean sea level height value, at Father Point, Rimouski, Quebec, Canada was held fixed, thus providing minimum constraint. NAVD 1988 and IGLD 1985 are not identical. However, NAVD 1988 bench mark values are given in Helmert orthometric height units while IGLD 1985 values are in dynamic heights. See International Great Lakes Datum of 1985, National Geodetic Vertical Datum of 1929, and geopotential difference.

North Atlantic Current—A North Atlantic Ocean current setting northeastward from southeast of the Grand Banks at about latitude 40° north, longitude 50° west, to the British Isles. A segment of the Gulf Stream System, the North Atlantic Current continues the flow of the Gulf Stream to the Norwegian and Canary Currents.

North Cape Current—An Arctic Ocean current setting eastward off the north coast of Scandinavia in the Barrents Sea.

North Equatorial Current—A current setting westward in the North Atlantic and North Pacific Oceans and in the Indian Ocean from about October to July. It occurs immediately north of the Equatorial Counter Current.

North Pacific Current—A North Pacific Ocean current setting eastward from about 160° east to somewhat beyond about 150° west. It continues the flow of the Kuroshio Extension, sending branches to the south.

Norwegian Current—A North Atlantic Ocean current setting northeastward off the coast of Norway.

nu (ν_2)—Larger lunar evectional constituent. See lambda.
Speed = $2T - 3s + 4h - p$ = 28.512,583,1° per solar hour.

O

O_1—Lunar diurnal constituent. See K_1.
Speed = $T - 2s + h$ = 13.943,035,6° per solar hour.

obliquity factor—A factor in an expression for a constituent tide (or tidal current) involving the angle of the inclination of the Moon's orbit to the plane of the Earth's Equator.

obliquity of the ecliptic—The angle which the ecliptic makes with the plane of the Earth's Equator. Its value is approximately 23.45°.

obliquity of the Moon's orbit—The angle which the Moon's orbit makes with the plane of the Earth's Equator. Its value varies from 18.3° to 28.6°, depending upon the longitude of the Moon's ascending node; the smaller value corresponding to a longitude of 180° and the larger one, to a longitude of 0°.

oceanography—Oceanography is the science of all aspects of the oceans, in spite of its etymology. The term, oceanography, implies the interrelationships of the various marine sciences of which it is composed. This connotation has arisen through the historical development of marine research in which it has been found that a true understanding of the oceans is best achieved through investigations based on the realization that water, its organic and inorganic contents, motions, and boundaries are mutually related and interdependent.

OO_1—Lunar diurnal, second-order, constituent.
Speed = $T + 2s + h$ = 16.139,101,7° per solar hour.

ordinary—With respect to tides, the use of this nontechnical word has, for the most part, been determined to be synonymous with mean. Thus, ordinary high (low) water is the equivalent of mean high (low) water. The use of ordinary in tidal terms is discouraged.

orifice—See stilling well and protective well.

overfalls—Breaking waves caused by the meeting of currents or by waves moving against the current. See rip.

overtide—A harmonic tidal (or tidal current) constituent with a speed that is an exact multiple of the speed of one of the fundamental constituents derived from the development of the tide-producing force. The presence of overtides is usually attributed to shallow water conditions. The overtides usually considered in tidal work are the harmonics of the principal lunar and solar semidiurnal constituents M_2 and S_2, and are designated by the symbols M_4, M_6, M_8, S_4, S_6, etc. The magnitudes of these harmonics relative to those of the fundamental constituents are usually greater in the tidal current than in the tide.

Oyashio—A current setting southwestward along the Siberian, Kamchatka, and Kuril Islands coasts in the Bering Sea and North Pacific Ocean.

P

p—Rate of change (as of January 1, 1900) in mean longitude of lunar perigee.
p = 0.004,641,83° per solar hour.

p_1—Rate of change (as of January 1, 1900) in mean longitude of solar perigee.
p_1 = 0.000,001,96° per solar hour.

P_1—Solar diurnal constituent. See K_1.
Speed = $T - h$ = 14.958,931,4° per solar hour.

parallax—In tidal work, the term refers to horizontal parallax, which is the angle formed at the center of a celestial body between a line to the center of the Earth and a line tangent to the Earth's surface. Since the sine of a small angle is approximately equal to the angle itself in radians, it is usually taken in tidal work simply as the ratio of the mean radius of the Earth to the distance of the tide-producing body. Since the parallax is a function of the distance of a celestial body, the term is applied to tidal inequalities arising from the changing distance of the tide-producing body.

parallax inequality—The variation in the range of tide or in the speed of a tidal current due to changes in the distance of the Moon from the Earth. The range of tide and speed of the current tend alternately to increase and decrease as the Moon approaches its perigee and apogee, respectively, the complete cycle being the anomalistic month. There is a similar but relatively unimportant inequality due to the Sun, the cycle being the anomalistic year. The parallax has little direct effect upon the lunitidal intervals but tends to modify the phase effect. When the Moon is in perigee, the priming and lagging of the tide due to the phase is diminished and when in apogee the priming and lagging is increased.

parallax reduction—A processing of observed high and low waters to obtain quantities depending upon changes in the distance of the Moon, such as perigean and apogean ranges.

parallel plate intake—Intake of a stilling or protective well with two parallel plates attached below. The plates are typically three times the diameter of the well and are spaced three inches apart. The plates are used to minimize current-induced draw-down (Bernoulli effect) error in water level measurements.

pelorus—An instrument formerly used on a vessel in connection with a current line and current pole to obtain the set of the current. In its simplest form, it was a disk about 8 inches in diameter and graduated clockwise for every 5° or 10° . It was mounted rigidly on the vessel, usually with the 0° mark forward and the diameter through this mark parallel with the keel. Bearings were then related to the vessel's compass and converted to true.

perigean tides or tidal currents—Tides of increased range or tidal currents of increased speed occurring monthly as the result of the Moon being in perigee. The perigean range (Pn) of tide is the average range occurring at the time of perigean tides and is most conveniently computed from the harmonic constants. It is larger than the mean range where the type of tide is either semidiurnal or mixed, and is of no practical significance where the type of tide is predominantly diurnal.

perigee—The point in the orbit of the Moon or a man-made satellite nearest to the Earth. The point in the orbit of a satellite nearest to its companion body.

perihelion—The point in the orbit of the Earth (or other planet, etc.) nearest to the Sun.

period—Interval required for the completion of a recurring event, such as the revolution of a celestial body or the time between two consecutive like phases of the tide or tidal current. A period may be expressed in angular measure as 360°. The word also is used to express any specified duration of time.

permanent current—A current that runs continuously and is independent of tides and other temporary causes. Permanent currents include the general surface circulation of the oceans.

Peru Current—A South Pacific Ocean current setting northward along the west coast of South America. It has sometimes been called the Humboldt Current because an early record of its temperature was taken by the German scientist Alexander von Humboldt in 1802. It has also been called the Peruvian or Chilean Current. The name Corriente de Peru was adopted by a resolution of the Ibero-American Oceanographic Conference at its Madrid-Malaga meeting in April 1935.

phase—(1) Any recurring aspect of a periodic phenomenon, such as new Moon, high water, flood strength, etc. (2) A particular instant of a periodic function expressed in angular measure and reckoned from the time of its maximum value, the entire period of the function being 360°. The maximum and minimum of a harmonic constituent have phase values of 0° and 180°, respectively.

phase inequality—Variations in the tides or tidal currents due to changes in the phase of the Moon. At the times of new and full Moon the tide-producing forces of the Moon and Sun act in conjunction, causing the range of tide and speed of the tidal current to be greater than the average, the tides at these times being known as spring tides. At the times of the quadratures of the Moon these forces are opposed to each other, causing neap tides with diminished range and current speed.

phase lag—Same as epoch (1).

phase reduction—A processing of observed high and low waters to obtain quantities depending upon the phase of the Moon, such as the spring and neap ranges of tide. At a former time this process was known as second reduction. Also applicable to tidal currents.

pororoca—Brazilian for tidal bore.

PORTS—**P**hysical **O**ceanographic **R**eal **T**ime **S**ystem. A national system of current, water level, and other oceanographical and meteorological sensors telemetering data in real-time to central locations for storage, processing, and dissemination. Available to pilots, mariners, the U.S. Coast Guard, and other marine interests in voice or digital form. First introduced in Tampa Bay.

potential, tide-producing—Tendency for particles on the Earth to change their positions as a result of the gravitational interactions between the Sun, Moon, and Earth. Although gravitational attraction varies inversely as the square of the distance of the tide producing body, the resulting potential varies inversely as the cube of the distance.

predicting machine—See tide predicting machine.

pressure gauge—A water level gauge that is operated by the change in pressure at the bottom of a body of water due to the rise and fall of the water level. See gas purged pressure gauge.

pressure gradient force, horizontal—The horizontal component of the product of the specific volume and the rate of decrease in pressure with distance.

pressure sensor—A pressure transducer sensing device for water level measurement. A relative transducer is vented to the atmosphere and pressure readings are made relative to atmospheric pressure. An absolute transducer measures the pressure at its location. The readings are then corrected for barometric pressure taken at the surface.

primary control tide station—A tide station at which continuous observations have been made over a minimum of 19 years. Its purpose is to provide data for computing accepted values of the harmonic and nonharmonic constants essential to tide predictions and to the determination of tidal datums for charting and for coastal and marine boundaries. The data series from this station serves as a primary control for the reduction of relatively short series from subordinate tide stations through the method of comparison of simultaneous observations and for monitoring long-period sea level trends and variations. See tide station, secondary control tide station, tertiary tide station, and subordinate tide station (1).

primary tidal bench mark—See bench mark.

prime meridian—The meridian of longitude which passes through the original site of the Royal Observatory in Greenwich, England and used as the origin of longitude. Also known as the Greenwich Meridian.

priming of tide—The periodic acceleration in the time of occurrence of high and low waters due to changes in the relative positions of the Sun and Moon.

progressive wave—A wave that advances in distance along the sea surface or at some intermediate depth. Although the wave form itself travels significant distances, the water particles that make up the wave merely describe circular (in relatively deep water) or elliptical (in relatively shallow water) orbits. With high, steep, wind waves, a small overlap in the orbital motion becomes significant. This overlapping gives rise to a small net mass transport. See long shore current and rip current. Progressive waves can be internal, traveling along a sharp density discontinuity, such as the thermocline, or in a layer of gradually changing density (vertically).

protective well—A vertical pipe with a relatively large opening (intake) in the bottom. It is used with the air acoustic ranging sensor and electronic processing (filtering) technique to minimize the nonlinear characteristics of the stilling well. Its purpose is also to shield the sensing element from physical damage and harsh environment. Unlike a stilling well, damping of high frequency waves is not a critical requirement. See stilling well.

pycnocline—A layer in which the density increases significantly (relative to the layers above and below) with depth.

Q

Q_1—Larger lunar elliptic diurnal constituent. See M_1. Speed = T − 3s + h + p = 13.398,660,9° per solar hour.

$2Q_1$—Lunar elliptic diurnal, second order, constituent. Speed = T − 4s + h + 2p = 12.854,286,2° per solar hour.

quadrature of Moon—Position of the Moon when its longitude differs by 90° from the longitude of the Sun. The corresponding phases are known as first quarter and last quarter.

R

R_2—Smaller solar elliptic constituent. This constituent, with T_2, modulates the amplitude and frequency of S_2 for the effect of variation in the Earth's orbital speed due to its elliptical orbit.
Speed = 2T + h − p_1 = 30.041,066,7° per solar hour.

race—A very rapid current through a comparatively narrow channel.

radiational tide—Periodic variations in sea level primarily related to meteorological changes such as the semidaily (solar) cycle in barometric pressure, daily (solar) land and sea breezes, and seasonal (annual) changes in temperature. Other changes in sea level due to meteorological changes that are random in phase are not considered radiational tides.

range of tide—The difference in height between consecutive high and low waters. The mean range is the difference in height between mean high water and mean low water. The great diurnal range or diurnal range is the difference in height between mean higher high water and mean lower low water. For other ranges see spring, neap, perigean, apogean, and tropic tides; and tropic ranges.

real-time—Pertains to a data collecting system that monitors an on-going process and disseminates measured values before they are expected to have changed significantly.

rectilinear current—Same as reversing current.

red tide (water)—The term applied to toxic algal blooms caused by several genera of dinoflagellates (*Gymnodinium* and *Gonyaulax*) which turn the sea red and are frequently associated with a deterioration in water quality. The color occurs as a result of the reaction of a red pigment, peridinin, to light during photosynthesis. These toxic algal blooms pose a serious threat to marine life and are potentially harmful to humans. The term has no connection with astronomic tides. However, its association with the word "tide" is from popular observations of its movements with tidal currents in estuarine waters.

reduction factor (F)—Reciprocal of node factor (f).

reduction of tides or tidal currents—A processing of observed tide or tidal current data to obtain mean values for tidal or tidal current constants.

reference station—A tide or current station for which independent daily predictions are given in the "Tide Tables" and "Tidal Current Tables," and from which corresponding predictions are obtained for subordinate stations by means of differences and ratios. See subordinate tide station (2) and subordinate current station (2).

relative mean sea level change—A local change in mean sea level relative to a network of bench marks established in the most stable and permanent material available (bedrock, if possible) on the land adjacent to the tide station location. A change in relative mean sea level may be composed of both an absolute mean sea level change component and a vertical land movement change component.

residual current—The observed current minus the astronomical tidal current.

response analysis—For any linear system, an input function $X_i(t)$ and an output function $X_0(t)$ can be related according to the formula:

$$X_0(t) = {}_0\int^{\infty} X_i(t-\tau)W(\tau)d\tau + \text{noise}(t)$$

where $W(\tau)$ is the impulse response of the system and its Fourier transform:

$$Z(f) = {}_0\int^{\infty} W(\tau)e^{-2\pi i f \tau} = R(f)e^{i\phi(f)}$$

is the system's admittance (coherent output/input) at

frequency f. In practice, the integrals are replaced by summations; X_i, W, and Z are generally complex. The discrete set of W values are termed response weights; $X_0(t)$ is ordinarily an observed tidal time series and $X_i(t)$ the tide potential or the tide at some nearby place. A future prediction can be prepared by applying the weights to an appropriate $X_i(t)$ series. In general:
$| Z | = R(f)$ and $Tan(Z) = \phi(f)$
measure the relative magnification and phase lead of the station at frequency f.

reversing current—A tidal current which flows alternately in approximately opposite directions with a slack water at each reversal of direction. Currents of this type usually occur in rivers and straits where the direction of flow is more or less restricted to certain channels. When the movement is towards the shore or up a stream, the current is said to be flooding, and when in the opposite direction, it is said to be ebbing. The combined flood and ebb movement (including the slack water) covers, on an average, 12.42 hours for a semidiurnal current. If unaffected by a nontidal flow, the flood and ebb movements will each last about 6 hours, but when combined with such a flow, the durations of flood and ebb may be quite different. During the flow in each direction the speed of the current will vary from zero at the time of slack water to a maximum about midway between the slacks.

reversing falls—A name applied to falls which flow alternately in opposite directions in a narrow channel in the St. John River above the city of St. John, New Brunswick, Canada, the phenomenon being due to the large range of tide and a constriction in the river. The direction of flow is upstream or downstream according to whether it is high or low water on the outside, the falls disappearing at the half-tide level.

rho (ρ_1)—Larger lunar evectional diurnal constituent.
Speed = $T - 3s + 3h - p$ = 13.471,514,5° per solar hour.

rip—Agitation of water caused by the meeting of currents or by a rapid current setting over an irregular bottom. Termed tide rip when a tidal current is involved. See overfalls.

rip current—A narrow intense current setting seaward through the surf zone. It removes the excess water brought to the zone by the small net mass transport of waves. It is fed by longshore currents. Rip currents usually occur at points, groins, jetties, etc., of irregular beaches, and at regular intervals along straight, uninterrupted beaches.

river current—The gravity-induced seaward flow of fresh water originating from the drainage basin of a river. In the fresh water portion of the river below head of tide, the river current is alternately increased and decreased by the effect of the tidal current. After entering a tidal estuary, river current is the depth-averaged mean flow through any cross-section. See head of tide and estuary.

river estuary—See estuary.

rotary current—A tidal current that flows continually with the direction of flow changing through all points of the compass during the tidal period. Rotary currents are usually found offshore where the direction of flow is not restricted by any barriers. The tendency for the rotation in direction has its origin in the Coriolis force and, unless modified by local conditions, the change is clockwise in the Northern Hemisphere and counterclockwise in the Southern. The speed of the current usually varies throughout the tidal cycle, passing through the two maxima in approximately opposite directions and the two minima with the direction of the current at approximately 90° from the directions of the maxima.

S

s—Rate of change (as of January 1, 1900) in mean longitude of Moon.
s = 0.549,016,53° per solar hour.

S_1—Solar diurnal constituent.
Speed = T = 15.000,000,0° per solar hour.

S_2—Principal solar semidiurnal constituent. This constituent represents the rotation of the Earth with respect to the Sun.
Speed = 2T = 30.000,000,0° per solar hour.

S_4, S_6—Shallow water overtides of the principal solar constituent.
Speed of $S_4 = 2S_2 = 4T$ = 60.000,000,0° per solar hour.
Speed of $S_6 = 3S_2 = 6T$ = 90.000,000,0° per solar hour.

Sa—Solar annual constituent. This constituent, with Ssa, accounts for the nonuniform changes in the Sun's declination and distance. In actuality, they mostly reflect yearly meteorological variations influencing sea level.
Speed = h = 0.041,068,64° per solar hour.

Ssa—Solar semiannual constituent. See Sa.
Speed = 2h = 0.082,137,3° per solar hour.

salinity (S)—The total amount of solid material in grams contained in 1 kilogram of sea water when all the carbonate has been converted to oxide, the bromine and iodine replaced by chlorine, and all organic matter completely oxidized. The following is approximate.
S(‰) = 1.806,55 x Cl (‰)
Where Cl(‰) is chlorinity in parts per thousand. See chlorinity.

Sargasso Sea—The west central region of the subtropical gyre of the North Atlantic Ocean. It is bounded by the North Atlantic, Canary, North Equatorial, and Antilles Currents, and the Gulf Stream. It is characterized by the absence of any well-marked currents and by large quantities of drifting Sargassum, or gulfweed.

Saros—A period of 223 synodic months corresponding approximately to 19 eclipse years or 18.03 Julian years, and is a cycle in which solar and lunar eclipses repeat themselves under approximately the same conditions.

sea level datum (SLD)—An obsolete term. See National Geodetic Vertical Datum of 1929 and mean sea level.

second reduction—Same as phase reduction.

secondary control tide station—A tide station at which continuous observations have been made over a minimum period of 1 year but less than 19 years. The series is reduced by comparison with simultaneous observations from a primary control tide station. This station provides for a 365-day harmonic analysis including the seasonal fluctuation of sea level. See tide station, primary control tide station, tertiary tide station, and subordinate tide station (1).

secular trend—See apparent secular trend as preferred term.

seiche—A stationary wave usually caused by strong winds and/or changes in barometric pressure. It is found in lakes, semi-enclosed bodies of water, and in areas of the open ocean. The period of a seiche in an enclosed rectangular body of water is usually represented by the formula:

Period $(T) = 2L / \sqrt{gd}$

in which L is the length, d the average depth of the body of water, and g the acceleration of gravity. See standing wave.

seismic sea wave—Same as tsunami.

semidiurnal—Having a period or cycle of approximately one-half of a tidal day. The predominant type of tide throughout the world is semidiurnal, with two high waters and two low waters each tidal day. The tidal current is said to be semidiurnal when there are two flood and two ebb periods each day. A semidiurnal constituent has two maxima and two minima each constituent day, and its symbol is the subscript 2. See type of tide.

sequence of current—The order of occurrence of the four tidal current strengths of a day, with special reference as to whether the greater flood immediately precedes or follows the greater ebb.

sequence of tide—The order in which the four tides of a day occur, with special reference as to whether the higher high water immediately precedes or follows the lower low water.

set (of current)—The direction towards which the current flows.

shallow water constituent—A short-period harmonic term introduced into the formula of tidal (or tidal current) constituents to account for the change in the form of a tide wave resulting from shallow water conditions. Shallow water constituents include the overtides and compound tides.

shallow water wave—A wave is classified as a shallow water wave whenever the ratio of the depth (the vertical distance of the still water level from the bottom) to the wave length (the horizontal distance between crests) is less than 0.04. Such waves propagate according to the formula:

$C = \sqrt{gd}$

where C is the wave speed, g the acceleration of gravity, and d the depth. Tidal waves are shallow water waves.

shear—A quasi-horizontal layer moving at a different velocity relative to the layer directly below and/or above.

shoreline (coastline)—The intersection of the land with the water surface. The shoreline shown on charts represents the line of contact between the land and a selected water elevation. In areas affected by tidal fluctuations, this line of contact is the mean high water line. In confined coastal waters of diminished tidal influence, the mean water level line may be used. See coast line.

sidereal day—The time of the rotation of the Earth with respect to the vernal equinox. It equals approximately 0.997,27 of a mean solar day. Because of the precession of the equinoxes, the sidereal day thus defined is slightly less than the period of rotation with respect to the fixed stars, but the difference is less than a hundredth part of a second.

sidereal month—Average period of the revolution of the Moon around the Earth with respect to a fixed star, equal to 27.321,661 mean solar days.

sidereal time—This is usually defined by astronomers as the hour angle of the vernal equinox. The sidereal day is the interval between two successive upper transits of the vernal equinox. It is to be noted that when applied to the month and year the word sidereal has reference to motion with respect to the fixed stars, while the word tropical is used for motion with respect to the vernal equinox. Because of the precession of the equinox there is a slight difference.

sidereal year—Average period of the revolution of the Earth around the Sun with respect to a fixed star. Its length is approximately 365.256,4 mean solar days.

sigma-t (σ_t)—An expression of density as a function of temperature and salinity (at atmospheric pressure) in a convenient numerical form. See density.

$\sigma_t = (\rho_{s,t,p} - 1)1{,}000$

sigma-zero (σ_o)—An expression of density as a function of salinity (at atmospheric pressure and 0°C) in a convenient numerical form. See density.

$\sigma_o = (\rho_{s,t,o} - 1)1{,}000$

slack; ebb begins (slack before ebb)—The slack water immediately preceding the ebb current.

slack; flood begins (slack before flood)—The slack water immediately preceding the flood current.

slack water (slack)—The state of a tidal current when its speed is near zero, especially the moment when a reversing current changes direction and its speed is zero. The term also is applied to the entire period of low speed near the time of turning of the current when it is too weak to be of any practical importance in navigation. The relation of the time of slack water to the tidal phases varies in different localities. For a perfect standing tidal wave, slack water occurs at the time of high and of low water, while for a perfect progressive tidal wave, slack water occurs midway between high and low water. See slack; ebb begins and slack; flood begins.

small diurnal range (Sl)—Difference in height between mean lower high water and mean higher low water.

small tropic range (Sc)—Difference in height between tropic lower high water and tropic higher low water.

solar day—The period of the rotation of the Earth with respect to the Sun. The mean solar day is the time of the rotation with respect to the mean Sun. The solar day commencing at midnight is called a civil or calendar day, but if the day is reckoned from noon it is known as an astronomical day because of its former use in astronomical calculation.

solar tide—(1) The part of the tide that is due to the tide-producing force of the Sun. (2) The observed tide in areas where the solar tide is dominant. This condition provides for phase repetition at about the same time each solar day.

solar time—Time measured by the hour angle of the Sun. It is called apparent time when referred to the actual Sun and mean time when referred to the mean Sun. It is also classified as local, standard, or Greenwich according to whether it is reckoned from the local, standard, or Greenwich meridian.

solitary wave—A wave of translation consisting of a single crest rising above the undisturbed water level without any accompanying trough. The rate of advance of a solitary wave depends upon the depth of the water and is usually expressed by the formula:

$C = \sqrt{g(d + h)}$

in which C = rate of advance, g = acceleration of gravity, d = depth of water, and h = height of wave, the depth and height being measured from the undisturbed water level.

solstices—The two points in the ecliptic where the Sun reaches its maximum and minimum declinations; also the times when the Sun reaches these points. The maximum north declination occurs on or near June 21, marking the beginning of summer in the Northern Hemisphere and the beginning of winter in the Southern. The maximum south declination occurs on or near December 22, marking the beginning of winter in the Northern Hemisphere and the beginning of summer in the Southern.

solstitial tides—Tides occurring near the times of the solstices. The tropic range may be expected to be especially large at these times.

Somali (East Africa Coast) Current—An Indian Ocean current setting southwestward along the coast of Somalia. The current reverses and sets to the northeast during the Southwest Monsoon.

South Equatorial Current—A current setting westward along and south of the Equator in the Atlantic and Pacific Oceans, and south of the Equator in the Indian Ocean. It occurs immediately south of the Equatorial Counter Current.

Southwest Monsoon Current—Same as Monsoon Current.

species of constituent—A classification depending upon the period of a constituent. The principal species are semidiurnal, diurnal, and long-period.

specific volume anomaly, or steric anomaly (δ)—The excess in specific volume over the standard specific volume at 35 ‰, 0°C, and the given pressure. See thermosteric anomaly and specific volume.

$\delta = \alpha_{s,t,p} - \alpha_{35,o,p}$

specific volume, in situ ($\alpha_{s,t,p}$)— Volume per unit mass. The reciprocal of density (specific gravity). The specific volume of sea water as a function of salinity, temperature, and pressure. See specific volume anomaly and thermosteric anomaly.

speed (of constituent)—The rate of change in the phase of a constituent, usually expressed in degrees per hour. The speed is equal to 360° divided by the constituent period expressed in hours.

speed (of current)—The magnitude of velocity. Rate at which the current flows. Usually expressed in knots or centimeters per second.

Spitsbergen Atlantic Current—A current setting northwestward off the southwest coast of Spitsbergen in the Greenland Sea.

spring high water—Same as mean high water springs (MHWS). See spring tides.

spring low water—Same as mean low water springs (MLWS). See spring tides and mean low water springs.

spring range (Sg)—See spring tides.

spring tides or tidal currents—Tides of increased range or tidal currents of increased speed occurring semimonthly as the result of the Moon being new or full. The spring range (Sg) of tide is the average range occurring at the time of spring tides and is most conveniently computed from the harmonic constants. It is larger than the mean range where the type of tide is either semi diurnal or mixed, and is of no practical significance where the type of tide is predominantly diurnal. The average height of the high waters of the spring tides is called spring high water or mean high water springs (MHWS) and the average height of the corresponding low waters is called spring low water or mean low water springs (MLWS).

stand of tide—Sometimes called a platform tide. An interval at high or low water when there is no sensible change in the height of the tide. The water level is stationary at high and low water for only an instant, but the change in level near these times is so slow that it is not usually perceptible. In general, the duration of the apparent stand will depend upon the range of tide, being longer for a small range than for a large range, but where there is a tendency for a double tide the stand may last for several hours even with a large range of tide.

standard method—A tidal datum computation method. Generally used for the West Coast and Pacific Island stations. Values needed are mean tide level (MTL), mean range of tide (MN), great diurnal range (GT), and mean diurnal high and low water inequalities (DHQ and DLQ) as determined by comparison with an appropriate control. From those, the following are computed:

MLW = MTL - (0.5*MN)
MHW = MLW + MN
MLLW = MLW - DLQ
MHHW = MHW + DHQ

standard time—A kind of time based upon the transit of the Sun over a certain specified meridian, called the time meridian, and adopted for use over a considerable area. With a few exceptions, standard time is based upon some meridian which differs by a multiple of 15° from the meridian of Greenwich. The United States first adopted standard time in 1883 on the initiative of the American Railway Association, and at noon on November 18 of that year the telegraphic time signals from the Naval Observatory at Washington were changed to this system.

standing (stationary) wave—A wave that oscillates without progressing. One-half of such a wave may be illustrated by the oscillation of the water in a pan that has been tilted. Near the axis, which is called the node or nodal line, there is no vertical rise and fall of the water. The ends of the wave are called loops and at these places the vertical rise and fall is at a maximum. The current is maximum near the node and minimum at the loops. The period of a stationary wave depends upon the length and depth of the body of water and, for a simple rectangular basin, may be expressed by the formula:

$T = 2L / \sqrt{gd}$

in which T is the period of wave, L the length of the basin, d the depth of water, and g the acceleration of gravity. A stationary wave may be resolved into two progressive waves of equal amplitude and equal speeds moving in opposite directions.

station datum—See datum of tabulation.

stationary wave theory—An assumption that the basic tidal movement in the open ocean consists of a system of stationary wave oscillations, any progressive wave movement being of secondary importance except as the tide advances into tributary waters. The continental masses divide the sea into irregular basins, which, although not completely enclosed, are capable of sustaining oscillations which are more or less independent. The tide-producing force consists principally of two parts, a semidiurnal force with a period of approximately half a day and a diurnal force with a period of approximately a whole day. Insofar as the free period of oscillation of any part of the ocean, as determined by its dimensions and depth, is in accord with the semidiurnal or diurnal tide-producing forces, there will be built up corresponding oscillations of considerable amplitude which will be manifested in the rise and fall of the tide. The diurnal oscillations, superimposed upon the semidiurnal oscillations, cause the inequalities in the heights of the two high and the two low waters of each day. Although the tidal movement as a whole is somewhat complicated by the overlapping of oscillating areas, the theory is consistent with observational data.

stencils—Perforated sheets formerly used with the tabulated hourly heights of the tide or speeds of the tidal current for the purpose of distributing and grouping them into constituent hours preliminary to summing for harmonic analysis. See Coast and Geodetic Survey Special Publication No. 98, Manual of Harmonic Analysis and Prediction of Tides. This analysis is now performed on electronic digital computers.

steric anomaly—Same as specific volume anomaly.

stilling well—A vertical pipe with a relatively small opening (intake) in the bottom. It is used in a gauge installation to dampen short period surface waves while freely admitting the tide, other long period waves, and sea level variations; which can then be measured by a water level gauge sensor inside. See float well and protective well.

storm surge—The local change in the elevation of the ocean along a shore due to a storm. The storm surge is measured by subtracting the astronomic tidal elevation from the total elevation. It typically has a duration of a few hours. Since wind generated waves ride on top of the storm surge (and are not included in the definition), the total instantaneous elevation may greatly exceed the predicted storm surge plus astronomic tide. It is potentially catastrophic, especially on low lying coasts with gently sloping offshore topography. See storm tide.

storm tide—As used by the National Weather Service, NOAA, the sum of the storm surge and astronomic tide. See storm surge.

stray line—Ungraduated portion of line connected with the current pole formerly used in taking current observations. The stray line was usually about 100 feet long and permitted the pole to acquire the velocity of the current at some distance from the disturbed waters in the immediate vicinity of the observing vessel, before the current velocity was read from the graduated portion of the current line.

strength of current—Phase of tidal current in which the speed is a maximum; also the speed at this time. Beginning with slack before flood in the period of a reversing tidal current (or minimum before flood in a rotary current), the speed gradually increases to flood strength and then diminishes to slack before ebb (or minimum before ebb in a rotary current), after which the current turns in direction, the speed increases to ebb strength and then diminishes to slack before flood, completing the cycle. If it is assumed that the speed throughout the cycle varies as the ordinates of a cosine curve, it can be shown that the average speed for an entire flood or ebb period is equal to $2/\pi$ or 0.636,6 of the speed of the corresponding strength of current.

strength of ebb—Same as ebb strength.

strength of flood—Same as flood strength.

submerged lands—Lands covered by water at any stage of the tide. See tidelands.

subordinate current station—(1) A current station from which a relatively short series of observations is reduced by comparison with simultaneous observations from a control current station. See current station, control current station, and reference station. (2) A station listed in the Tidal Current Tables for which predictions are to be obtained by means of differences and ratios applied to the full predictions at a reference station. See reference station.

subordinate tide station—(1) A tide station from which a relatively short series of observations is reduced by comparison with simultaneous observations from a tide station with a relatively long series of observations. See tide station, primary control tide station, secondary control tide station, and tertiary tide station. (2) A station listed in the Tide Tables from which predictions are to be obtained by means of differences and ratios applied to the full predictions at a reference station. See reference station.

summer time—British name for daylight saving time.

synodical month—The average period of the revolution of the Moon around the Earth with respect to the Sun, or the average interval between corresponding phases of the Moon. The synodical month is approximately 29.530,588 days in length.

syzygy—With respect to tides, whenever the Moon is lined up with the Earth and Sun in a straight Sun-Moon-Earth or Sun-Earth-Moon configuration. At these times the range of tide is greater than average. See spring tides or tidal currents.

T

T—Rate of change of hour angle of mean Sun at place of observation.
T = 15° per mean solar hour.

T_2—Larger solar elliptic constituent. See R_2.
Speed = $2T - h + p_1$ = 29.958,933,3° per solar hour.

tape gauge—See electric tape gauge.

telemetry—The capability of transmitting or retrieving data over long distance communication links, such as satellite, VHF radio, or telephone.

terdiurnal—Having three periods in a constituent day. The symbol of a terdiurnal constituent is the subscript 3.

tertiary tide station—A tide station at which continuous observations have been made over a minimum period of 30 days but less than 1 year. The series is reduced by comparison with simultaneous observations from a secondary control tide station. This station provides for a 29-day harmonic analysis. See tide station, primary control tide station, secondary control tide station, and subordinate tide station (1).

thermocline—A layer in which the temperature decreases significantly (relative to the layers above and below) with depth. The principal ones are designated diurnal, seasonal, and main thermocline.

thermosteric anomaly(δ_T, Δ', or $\Delta_{s,t}$)—The specific volume anomaly (steric anomaly) that would be attained if the water were changed isothermally to a standard pressure of one atmosphere. The specific volume anomaly with pressure terms omitted. See isanostere.

tidal bench mark—See bench mark.

tidal bench mark description—A published, concise description of the location, stamped number or designation, date established, and elevation (referred to a tidal datum) of a specific bench mark.

tidal bench mark state index map—A state map which indicates the locations for which tidal datums and tidal bench mark descriptions are available.

tidal bore—A tidal wave that propagates up a relatively shallow and sloping estuary or river with a steep wave front. The leading edge presents an abrupt rise in level, frequently with continuous breaking and often immediately followed by several large undulations. An uncommon phenomenon, the tidal bore is usually associated with very large ranges in tide as well as wedge shaped and rapidly shoaling entrances. Also called eagre, eager (for Tsientan, China bore), mascaret (French), pororoca (Brazilian), and bore.

tidal characteristics—Principally, those features relating to the time, range, and type of tide.

tidal constants—Tidal relations that remain practically constant for any particular locality. Tidal constants are classified as harmonic and nonharmonic. The harmonic constants consist of the amplitudes and epochs of the harmonic constituents, and the nonharmonic constants include the ranges and intervals derived directly from the high and low water observations.

tidal constituent—See constituent.

tidal current—A horizontal movement of the water caused by gravitational interactions between the Sun, Moon, and Earth. The horizontal component of the particulate motion of a tidal wave. Part of the same general movement of the sea that is manifested in the vertical rise and fall called tide. The United States equivalent of the British tidal stream. See tidal wave, tide, and current.

Tidal Current Chart Diagrams—A series of monthly diagrams to be used with the Tidal Current Charts. Each diagram contains lines that indicate the specific tidal current chart to use for a given date and time, and the speed factor to apply to that chart.

Tidal Current Charts—Charts on which tidal current data are depicted. Tidal Current Charts for a number of important waterways are published by the National Ocean Service. Each consists of a set of charts giving the speed and direction of the current for each hour or equal interval of the tidal cycle, thus presenting a comprehensive view of the tidal current movement.

tidal current constants—See current constants.

tidal current station—See current station.

Tidal Current Tables—Tables which give daily predictions of the times and velocities of the tidal currents. These predictions are usually supplemented by current differences and constants through which predictions can be obtained for numerous other locations.

tidal datum—See datum.

tidal day—Same as lunar day.

tidal difference—Difference in time or height between a high or low water at a subordinate station and a reference station for which predictions are given in the Tide Tables. The difference, when applied according to sign to the prediction at the reference station, gives the corresponding time or height for the subordinate station.

tidal epoch—See National Tidal Datum Epoch and epoch.

tidal estuary—See estuary.

tidal stream—British equivalent of United States tidal current.

tidal wave—A shallow water wave caused by the gravitational interactions between the Sun, Moon, and Earth. Essentially, high water is the crest of a tidal wave and low water, the trough. Tidal current is the horizontal component of the particulate motion, while tide is manifested by the vertical component. The observed tide and tidal current can be considered the result of the combination of several tidal waves, each of which may vary from nearly pure progressive to nearly pure standing and with differing periods, heights, phase relationships, and direction.

tidal zoning—The practice of dividing a hydrographic survey area into discrete zones or sections, each one possessing similar tidal characteristics. One set of tide reducers is assigned to each zone. Tide reducers are used to adjust the soundings in that zone to chart datum (MLLW). Tidal zoning is necessary in order to correct for differing water level heights occurring throughout the survey area at any given time. Each zone of the survey area is geographically delineated such that the differences in time and range do not exceed certain limits, generally 0.2 hours and 0.2 feet respectively; however, these limits are subject to change depending upon type of survey, location, and tidal characteristics. The tide reducers are derived from the water levels recorded at an appropriate tide station, usually nearby. Tide reducers are used to correct the soundings throughout the hydrographic survey area to a common, uniform, uninterrupted chart datum. See tide reducers.

tide—The periodic rise and fall of a body of water resulting from gravitational interactions between Sun, Moon, and Earth. The vertical component of the particulate motion of a tidal wave. Although the accompanying horizontal movement of the water is part of the same phenomenon, it is preferable to designate this motion as tidal current. See tidal wave.

tide curve—A graphic representation of the rise and fall of the tide in which time is usually represented by the abscissa and height by the ordinate. For a semidiurnal tide with little diurnal inequality, the graphic representation approximates a cosine curve. See marigram.

tide datum—See datum.

tide (water level) gauge—An instrument for measuring the rise and fall of the tide (water level). See ADR gauge, automatic tide gauge, Next Generation Water Level Measurement System, gas purged pressure gauge, electric tape gauge, pressure gauge, and tide staff.

tide predicting machine—A mechanical analog machine especially designed to handle the great quantity of constituent summations required in the harmonic method. William Ferrel's Maxima and Minima Tide Predictor (described in Manual of Tides, U.S. Coast and Geodetic Survey, Appendix 10, Report for 1883) was the first such machine used in the United States. Summing only 19 constituents, but giving direct readings of the predicted times and heights of the high and low waters, the Ferrel machine was used for the predictions of 1885 through 1914. A second machine, developed by Rollin A. Harris and E. G. Fischer and summing 37 constituents, was used for the predictions of 1912 through 1965 (described in Manual of Harmonic Analysis and Prediction of Tides by Paul Schureman, U.S. Coast and Geodetic Survey Special Publication No. 98, 1958). Predictions are now prepared using an electronic digital computer.

tide-producing force—That part of the gravitational attraction of the Moon and Sun which is effective in producing the tides on the Earth. The force varies approximately as the mass of the attracting body and inversely as the cube of its distance. The tide-producing force exerted by the Sun is a little less than one-half as great as that of the Moon. A mathematical development of the vertical and horizontal components of the tide-producing forces of the Moon and Sun will be found in Coast and Geodetic Survey Special Publication No. 98.

tide reducers—Height corrections for reducing soundings to chart datum (MLLW). A tide reducer represents the height of the water level at a given place and time relative to chart datum. Tide reducers are obtained from one or more tide stations within or nearby the survey area. Often, due to differing tidal characteristics over the survey area, the tide reducers obtained directly from a tide station must be corrected to adjust for time and range of tide differences in the various zones of the hydrographic survey area. See tidal zoning.

tide rip—See rip.

tide staff—A water level gauge consisting of a vertical graduated staff from which the height of the water level can be read directly. It is called a fixed staff when secured in place so that it cannot be easily removed. A portable staff is one that is designed for removal from the water when not in use. For such a staff a fixed support is provided. The support has a metal stop secured to it so that the staff will always have the same elevation when installed for use. See electric tape gauge.

tide (water level) station—The geographic location at which tidal observations are conducted. Also, the facilities used to make tidal observations. These may include a tide house, tide (water level) gauge, tide staff, and tidal bench marks. See primary control tide station, secondary control tide station, tertiary tide station, and subordinate tide station (1).

Tide Tables—Tables which give daily predictions of the times and heights of high and low waters. These predictions are usually supplemented by tidal differences and constants through which predictions can be obtained for numerous other locations.

tide wave—See tidal wave.

tidelands—The zone between the mean high water and mean low water lines. It is identical with intertidal zone (technical definition) when the type of tide is semidiurnal or diurnal.

tidewater—Water activated by the tide generating forces and/or water affected by the resulting tide, especially in coastal and estuarine areas. Also, a general term often applied to the land and water of estuarine areas formed by postglacial drowning of coastal plain rivers.

tideway—A channel through which a tidal current flows.

time—Time is measured by the rotation of the Earth with respect to some point in the celestial sphere and may be designated as sidereal, solar, or lunar, according to whether the measurement is taken in reference to the vernal equinox, the Sun, or the Moon. Solar time may be apparent or mean, according to whether the reference is to the actual Sun or the mean Sun. Mean solar time may be local or standard, according to whether it is based upon the transit of the Sun over the local meridian or a selected meridian adopted as a standard over a considerable area. Greenwich time is standard time based upon the meridian of Greenwich. In civil time the day commences at midnight, while in astronomical time, as used prior to 1925, the beginning of the day was reckoned from noon of the civil day of the same date. The name universal time is now applied to Greenwich mean civil time.

time meridian—A meridian used as a reference for time.

total current—The combination of the tidal and non-tidal current. The United States equivalent of the British flow. See current.

tractive force—The horizontal component of a tide-producing force vector (directed parallel with level surfaces at that geographic location).

transit—The passage of a celestial body over a specified meridian. The passage is designated as upper transit or lower transit according to whether it is over that part of the meridian lying above or below the polar axis.

tropic currents—Tidal currents occurring semimonthly when the effect of the Moon's maximum declination is greatest. At these times the tendency of the Moon to produce a diurnal inequality in the current is at a maximum.

tropic inequalities—Tropic high water inequality (HWQ) is the average difference between the two high waters of the day at the times of tropic tides. Tropic low water inequality (LWQ) is the average difference between the two low waters of the day at the times of tropic tides. These terms are applicable only when the type of tide is semidiurnal or mixed. See tropic tides.

tropic intervals—Tropic higher high water interval (TcHHWI) is the lunitidal interval pertaining to the higher high waters at the time of the tropic tides. Tropic lower low water interval (TcLLWI) is the lunitidal interval pertaining to the lower low waters at the time of the tropic tides. Tropic intervals are marked a when reference is made to the upper transit of the Moon at its north declination or to the lower transit at the time of south declination, and are marked b when the reference is to the lower transit at the north declination or to the upper transit at the south declination. See tropic tides.

tropic ranges—The great tropic range (Gc), or tropic range, is the difference in height between tropic higher high water and tropic lower low water. The small tropic range (Sc) is the difference in height between tropic lower high water and tropic higher low water. The mean tropic range (Mc) is the mean between the great tropic and the small tropic range. Tropic ranges are most conveniently computed from the harmonic constants. See tropic tides.

tropic speed—The greater flood or greater ebb speed at the time of tropic currents.

tropic tides—Tides occurring semimonthly when the effect of the Moon's maximum declination is greatest. At these times there is a tendency for an increase in the diurnal range. The tidal datums pertaining to the tropic tides are designated as tropic higher high water (TcHHW), tropic lower high water (TcLHW), tropic higher low water (TcHLW), and tropic lower low water (TcLLW).

tropical month—The average period of the revolution of the Moon around the Earth with respect to the vernal equinox. Its length is approximately 27.321,582 days.

tropical year—The average period of the revolution of the Earth around the Sun with respect to the vernal equinox. Its length is approximately 365.242,2 days. The tropical year determines the cycle of changes in the seasons, and is the unit to which the calendar year is adjusted through the occasional introduction of the extra day on leap years.

trough—The lowest point in a propagating wave. See low water and tidal wave.

true direction—Direction relative to true north (0°) which is the direction of the north geographic pole. See compass direction and magnetic direction.

tsunami—A shallow water progressive wave, potentially catastrophic, caused by an underwater earthquake or volcano.

Tsushima Current—A North Pacific Ocean current setting northeastward in the East China Sea (in summer) and Sea of Japan. A segment of the Kuroshio System.

type of tide—A classification based on characteristic forms of a tide curve. Qualitatively, when the two high waters and two low waters of each tidal day are approximately equal in height, the tide is said to be semidiurnal; when there is a relatively large diurnal inequality in the high or low waters or both, it is said to be mixed; and when there is only one high water and one low water in each tidal day, it is said to be diurnal. Quantitatively (after Dietrich), where the amplitude ratio of $K_1 + O_1$ to $M_2 + S_2$ is less than 0.25, the tide is classified as semidiurnal; where the ratio is from 0.25 to 1.5, the tide is mixed, mainly semidiurnal; where the ratio is from 1.5 to 3.0, the tide is mixed, mainly diurnal; and where greater than 3.0, diurnal.

U

universal time (UT)—Same as Greenwich mean time (GMT). See time, kinds.

uplands— Land above the mean high water line (shoreline) and subject to private ownership, as distinguished from tidelands, the ownership of which is prima facie in the state but also subject to divestment under state statutes. See tidelands.

upwelling—An upward flow of subsurface water due to such causes as surface divergence, offshore wind, and wind drift transport away from shore.

V

V_0 + u—See equilibrium argument.

vanishing tide—In a predominantly mixed tide with a very large diurnal inequality, the lower high water and higher low water become indistinct (or vanish) at times of extreme declinations.

variation (of compass)—Difference between true north as determined by the Earth's axis of rotation and magnetic north as determined by the Earth's magnetism. Variation is designated as east or positive when the magnetic needle is deflected to the east of true north and as west or negative when the deflection is to the west of true north. The variation changes with time. Also called magnetic declination.

variational inequality—An inequality in the Moon's motion due mainly to the tangential component of the Sun's attraction.

velocity (of current)—Speed and set of the current.

vernal equinox—See equinoxes.

vulgar establishment—Same as establishment of the port.

W

water level gauge—See tide gauge.

water level station—See tide station.

wave height—The vertical distance between crest and trough. See range of tide.

West Australian Current—An Indian Ocean current setting northward along the west coast of Australia.

West Greenland Current—A North Atlantic Ocean current setting northward along the west coast of Greenland.

West Wind Drift—Same as Antarctic Circumpolar Current.

wind drift—An ocean current in which only the Coriolis and frictional forces are significant. The wind drift embodies an Ekman spiral.

Z

Z_O—Symbol recommended by the International Hydrographic Organization to represent the elevation of mean sea level above chart datum.

Message

From: Dean, Heather [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=544264942F0644FEAF7C86ABAEBCD3DF-DEAN, HEATHER]
Sent: 7/27/2015 11:09:14 PM
To: Linda Storm [Storm.Linda@epa.gov]
Subject: Revised HTL vs MHHW Table
Attachments: HTLvsMHHW.xlsx

Here you go....

Message

From: Dean, Heather [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=544264942F0644FEAF7C86ABAEBCD3DF-DEAN, HEATHER]
Sent: 5/9/2016 4:33:57 PM
To: Meyer, Susan [meyer.susan@epa.gov]
Subject: RE: Beach profiles by the Corps for HTL

Works for me; I'll definitely defer to those who have already been to the sites. Thanks!

From: Meyer, Susan
Sent: Monday, May 09, 2016 9:32 AM
To: Szerlog, Michael <Szerlog.Michael@epa.gov>; Murchie, Peter <Murchie.Peter@epa.gov>; Dean, Heather <Dean.Heather@epa.gov>; Szalay, Endre <Szalay.Endre@epa.gov>
Subject: Beach profiles by the Corps for HTL

Hi all,

Remember on our call with the Corps last Wed., we said we would help identify beach segments that the Corps' GIS guy (Lawrence, I think) could do elevation surveys on. We said we would have the areas for him on Friday, which I don't think we did.

After our field day last Thursday, Tim, Phill and I thought that three field sites is too many for one day (I left the office at 7:45pm), and that we should focus on Seattle and Tulalip. I think Lawrence could get three good transects from Seattle and Tulalip. Heather, Tim and I are meeting in person on Thursday and can mark down areas that we think would work given the criteria outlined at the meeting. Let me know if you think this is okay, or if we should do this earlier in the week. I can let Jim J. know this as well, if that works.

Thanks,
Susan Meyer
EPA Region 10
Puget Sound and National Estuary Programs
1200 6th Aveune, Suite 900
Seattle, Washington 98101-3140
206-553-1078
Meyer.susan@epa.gov

Message

From: Dean, Heather [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=544264942F0644FEAF7C86ABAEBCD3DF-DEAN, HEATHER]
Sent: 10/20/2015 6:07:50 PM
To: Michael Szerlog [Szerlog.Michael@epa.gov]
Subject: FW: Info on HTL
Attachments: What is the HTL.docx; HTLvsMHHW.xlsx

Oh, & I also have all of the WA tide stations mapped in Google Earth, showing which ones have HAT & which ones don't.

From: Dean, Heather
Sent: Tuesday, October 20, 2015 11:06 AM
To: Michael Szerlog
Subject: Info on HTL

Good morning. Given Dave Gesl's intent *not* to talk about what datum to use for HTL, we may not use these, but I've attached two documents that we could show (first two pages only, for the Word doc), if, by some chance we do talke about it. We can also go to any of the links in the Word doc.

As for the info you wanted me to follow up on:

Deliberative Process / Ex. 5

I think that's it for now. Let me know if you want to discuss.

Message

From: Dean, Heather [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=544264942F0644FEAF7C86ABAEBCD3DF-DEAN, HEATHER]
Sent: 9/7/2016 2:24:14 PM
To: Whitley, Annie [Whitley.Annie@epa.gov]
Subject: RE: HTL Report

You're welcome! MS wanted to hold off sharing it more widely just yet.

From: Whitley, Annie
Sent: Thursday, September 01, 2016 3:50 PM
To: Dean, Heather <Dean.Heather@epa.gov>
Subject: RE: HTL Report

Thanks Heather! ☺

From: Dean, Heather
Sent: Thursday, September 01, 2016 8:03 AM
To: Whitley, Annie <Whitley.Annie@epa.gov>
Subject: HTL Report

Hi, Annie. I'm attaching the HTL report for you. I need to check with Michael first about sharing it more broadly. **Deliberative Process / Ex. 5** I'll let you know.

Message

From: Dean, Heather [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=544264942F0644FEAF7C86ABAEBCD3DF-DEAN, HEATHER]
Sent: 9/1/2016 8:27:24 PM
To: Tyson, Linda [Tyson.Linda@epa.gov]
CC: Michael Szerlog [Szerlog.Michael@epa.gov]
Subject: Briefing Paper for Dennis-High Tide Line
Attachments: RA Briefing-HTL vs MHHW-final.docx

Hi, Linda.

Attached is a briefing paper for OERA's (& others') meeting with Dennis next Wednesday, at 3 p.m. Please let me know if I/we need to provide anything else.

Thanks,

Heather

Message

From: Dean, Heather [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=544264942F0644FEAF7C86ABAEBCD3DF-DEAN, HEATHER]
Sent: 9/1/2016 8:25:41 PM
To: Allnutt, David [Allnutt.David@epa.gov]
Subject: RE: Revised HTL Briefing Paper for Dennis

Thanks, David.

I left a message for Endre about your question. I'll let you know what he says, unless he gets back to you directly.

P.S. Left a copy of the comic book in your reception area in-box.

From: Allnutt, David
Sent: Thursday, September 01, 2016 1:14 PM
To: Dean, Heather <Dean.Heather@epa.gov>; Murchie, Peter <Murchie.Peter@epa.gov>
Cc: Szerlog, Michael <Szerlog.Michael@epa.gov>
Subject: RE: Revised HTL Briefing Paper for Dennis

Heather – sorry to have missed both of your deadlines. A couple of edits and a question from me.

R. David Allnutt, Director
Office of Environmental Review and Assessment
U.S. EPA, Region 10
1200 Sixth Avenue, Suite 900
Seattle, Washington 98101-3140
(206) 553-2581

From: Dean, Heather
Sent: Thursday, September 01, 2016 8:18 AM
To: Allnutt, David <Allnutt.David@epa.gov>; Murchie, Peter <Murchie.Peter@epa.gov>
Cc: Szerlog, Michael <Szerlog.Michael@epa.gov>
Subject: Revised HTL Briefing Paper for Dennis

Good morning, gentlemen.

If you haven't already started reviewing the paper I sent yesterday, look at this one, instead. It incorporates a few edits from Endre & Susan.

Appointment

From: Dean, Heather [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=544264942F0644FEAF7C86ABAEBCD3DF-DEAN, HEATHER]
Sent: 7/13/2016 3:42:55 PM
To: Meyer, Susan [meyer.susan@epa.gov]

Subject: Accepted: HTL meeting today
Location: R10Sea-Room-20Chinook/R10-Rooms-Service-Center

Start: 7/13/2016 4:00:00 PM
End: 7/13/2016 6:00:00 PM
Show Time As: Busy

Message

From: Dean, Heather [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=544264942F0644FEAF7C86ABAEBCD3DF-DEAN, HEATHER]
Sent: 9/1/2016 4:26:02 PM
To: Brown, Donald M. [Brown.DonaldM@epa.gov]
Subject: High Tide Line Report

Hi, Donald. Michael Szerlog wants me to get the High Tide Line report that I spoke about yesterday into our library system. I've never done such a thing, but I see in the form that I need to ask you to review it, unless it's not considered a technical report, in which case the reviewer would be Charles Bert. Do you have enough info to advise whether it would be you or Charles, &, if not, what additional info can I give you?

Thanks,

Heather

Appointment

From: Dean, Heather [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=544264942F0644FEAF7C86ABAEBCD3DF-DEAN, HEATHER]
Sent: 7/16/2015 3:03:49 PM
To: Christensen, Damaris [Christensen.Damaris@epa.gov]

Subject: Tentative: discussion of Earthjustice request and HTL
Location: DCRoomWest7201/DC-CCW-OWOW

Start: 7/23/2015 3:30:00 PM
End: 7/23/2015 4:00:00 PM
Show Time As: Busy

Message

From: Dean, Heather [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=544264942F0644FEAF7C86ABAEBCD3DF-DEAN, HEATHER]
Sent: 3/7/2016 9:00:39 PM
To: Donna Downing [Downing.Donna@epa.gov]
CC: Michael Szerlog [Szerlog.Michael@epa.gov]; Szalay, Endre [Szalay.Endre@epa.gov]
Subject: HTL Materials
Attachments: HTL Matrix for WA Workgroup.docx; Graphic-Corps Datums (with MHW)-updated 7 Mar 16.pptx; Datums-Washington.pptx; Tide Station Data-7 Mar 16.xlsx

Hi, Donna. Thanks for the confab this morning! I'm attaching the various documents we looked at during the discussion, including:

1. A Word document ("HTL Matrix for WA Workgroup") that we have begun as part of our work with the Seattle District & NOAA Region 10 on the local HTL issue. It compares/will compare a suite of elevations to various parameters, including the regulatory definition, stated intent of HTL (from the Corps' preamble), & practical & ecological implications;
2. A PowerPoint file ("Graphic-Corps Datums (with MHW") with three slides, showing
    a. what elevations different Corps Districts use (shown by State);
    b. the same information in tabular form (& also including comments & information sources); &
    c. the proportional differences in elevation between HAT (highest astronomical tide), HPT (highest predicted/annual tide), MHHW, &, where used, MHW;
3. A PowerPoint file ("Datums-Washington") with two slides, showing the proportional differences HAT, HPT, & MHHW in
    a. WA state &
    b. the Puget Sound area;
4. An Excel file ("Tide Station Data") that compiles data from 587 harmonic tide stations around the country (out of a total of 847), including HAT, MHHW, highest annual tide for 2015, &, where used, MHW; the differences between them; & the differences between the averages for each state & for the country as a whole. To note:
    a. yellow cells in the table highlight stations for which NOAA has not published the HAT (73% of the harmonic stations have a published HAT);
    b. red cells highlight stations on the Columbia River, which have anomalous data i.e., much bigger difference between HAT & HPT than all other stations, which you can see on the first "Datums-Washington" slide); &
    c. orange cells highlight other anomalous or seemingly anomalous data/results.

Please let me know if you have any questions or comments or would like me to do something for you.

Until then,

Heather

Message

From: Dean, Heather [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=544264942F0644FEAF7C86ABAEBCD3DF-DEAN, HEATHER]
Sent: 5/3/2016 11:36:10 PM
To: Meyer, Susan [meyer.susan@epa.gov]
Subject: RE: Draft HTL Frequency Chart

Great; thanks for taking a look. I'll be working until 6:00.

From: Meyer, Susan
Sent: Tuesday, May 03, 2016 4:35 PM
To: Dean, Heather <Dean.Heather@epa.gov>
Cc: Szerlog, Michael <Szerlog.Michael@epa.gov>
Subject: RE: Draft HTL Frequency Chart

That looks great, Heather. Thanks – I think that shows it well.

Also, I plan to have the matrix (implications part) drafted by the end of today, but if you have a chance to look it over before the meeting tomorrow, great. I'm ccing Michael, since I understand you are only going be on the phone. Thanks!

From: Dean, Heather
Sent: Tuesday, May 03, 2016 3:06 PM
To: Meyer, Susan <meyer.susan@epa.gov>
Subject: RE: Draft HTL Frequency Chart

Hi, Susan.

So, it seems that I can bold the entire legend, but not just the station names. I did bold the whole thing.

Deliberative Process / Ex. 5

From: Meyer, Susan
Sent: Tuesday, May 03, 2016 9:59 AM
To: Dean, Heather <Dean.Heather@epa.gov>
Subject: RE: Draft HTL Frequency Chart

Heather, I like this chart. Since the main thing we want to exhibit **Deliberative Process / Ex. 5** **Deliberative Process / Ex. 5** I think it would help to bold the station names in the legend, so that the info in parens stands out more.

Deliberative Process / Ex. 5
Deliberative Process / Ex. 5 Thanks for doing this. My turn to work on the Matrix! Yikes!

My 2 cents!

Susan

From: Dean, Heather
Sent: Monday, May 02, 2016 3:59 PM
To: Szerlog, Michael <Szerlog.Michael@epa.gov>; Meyer, Susan <meyer.susan@epa.gov>; Murchie, Peter <Murchie.Peter@epa.gov>; Szalay, Endre <Szalay.Endre@epa.gov>
Subject: Draft HTL Frequency Chart

Hi, everyone. At our last HTL meeting, Craig & others noted that it would be nice to have a visual that showed the frequency of occurrence of various elevations. **Deliberative Process / Ex. 5** **Deliberative Process / Ex. 5**. Questions:

1) Does this chart fit the bill;
2) Is there anything we should change about it; &

Deliberative Process / Ex. 5 ice

Thanks,

Heather

Message

From: Dean, Heather [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=544264942F0644FEAF7C86ABAEBCD3DF-DEAN, HEATHER]
Sent: 9/10/2015 3:13:20 PM
To: Michael Szerlog [Szerlog.Michael@epa.gov]
Subject: HTL Stuff
Attachments: Determining High Tide Line.docx; Exceedance Probabilities.pptx; EM_1110-2-6056.pdf; HTLvsMHHW.xlsx

EM 1110-2-6056
31 December 2010

US Army Corps
of Engineers

ENGINEERING AND DESIGN

Standards and Procedures for Referencing Project Elevation Grades to Nationwide Vertical Datums

ENGINEER MANUAL

DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, DC 20314-1000

EM 1110-2-6056

CECW-CE

Manual
No. 1110-2-6056

31 December 2010

Engineering and Design
STANDARDS AND PROCEDURES FOR REFERENCING PROJECT ELEVATION GRADES TO NATIONWIDE VERTICAL DATUMS

1. Purpose. This manual provides technical guidance for referencing project elevation grades to nationwide vertical datums established and maintained by the U.S. Department of Commerce. It supplements ER 1110-2-8160 (*Policies for Referencing Project Elevation Grades to Nationwide Vertical Datums*) that requires controlling elevations and local datums on USACE projects shall be properly and accurately referenced to nationwide spatial reference systems used by other Federal, state, and local agencies responsible for flood forecasting, inundation modeling, water control, flood insurance rate maps, navigation charting, and topographic mapping.

2. Applicability. This manual applies to all USACE commands having responsibility for the planning, engineering, design, construction, operation, maintenance, and regulation of flood risk management, coastal storm damage reduction, hurricane protection, multi-purpose water supply/control, hydropower, regulatory, ecosystem restoration, and navigation projects.

3. Distribution. This publication is approved for public release; distribution is unlimited.

4. Discussion. ER 1110-2-8160 requires that the designed, constructed, and maintained elevation grades of USACE projects shall be reliably and accurately referenced to a consistent nationwide framework, or vertical datum—i.e., the National Spatial Reference System (NSRS) or the National Water Level Observation Network (NWLON) maintained by the U. S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA). This manual provides technical and procedural guidance for establishing the relationships for designed, constructed, or maintained project grades relative to these nationwide frameworks.

FOR THE COMMANDER:

13 Appendices
(See Table of Contents)

DIONYSIOS ANNINOS
Colonel, Corps of Engineers
Chief of Staff

DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

EM 1110-2-6056

CECW-CE

Manual
No. 1110-2-6056

31 December 2010

Engineering and Design
STANDARDS AND PROCEDURES FOR REFERENCING PROJECT ELEVATION GRADES TO NATIONWIDE VERTICAL DATUMS

TABLE OF CONTENTS

List of Figures Page

List of Figures | Page

List of Figures Page

List of Figures | Page

List of Figures Page

List of Figures Page

List of Figures | Page

List of Tables Page

List of Tables | Page

List of Tables | Page

CHAPTER 1

Introduction

1-1. Purpose. This manual provides technical guidance for referencing project elevation grades to nationwide vertical datums established and maintained by the U.S. Department of Commerce. It supplements ER 1110-2-8160 (*Policies for Referencing Project Elevation Grades to Nationwide Vertical Datums*) that requires controlling elevations and local datums on USACE projects shall be properly and accurately referenced to nationwide spatial reference systems used by other Federal, state, and local agencies responsible for flood forecasting, inundation modeling, water control, flood insurance rate maps, navigation charting, and topographic mapping.

1-2. Applicability. This manual applies to all USACE commands having responsibility for the planning, engineering, design, construction, operation, maintenance, and regulation of flood risk management, coastal storm damage reduction, hurricane protection, multi-purpose water supply/control, hydropower, regulatory, ecosystem restoration, and navigation projects.

1-3. Distribution. This publication is approved for public release; distribution is unlimited.

1-4. References. Referenced USACE publications and related bibliographic information are listed in Appendix A. Where applicable, primary source material for individual chapters may be noted within that chapter.

1-5. Discussion. ER 1110-2-8160 requires that the designed, constructed, and maintained elevation grades of USACE projects shall be reliably and accurately referenced to a consistent nationwide framework, or vertical datum—i.e., the National Spatial Reference System (NSRS) or the National Water Level Observation Network (NWLON) maintained by the U. S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA). This manual provides technical and procedural guidance for establishing the relationships for designed, constructed, or maintained project grades relative to these nationwide frameworks.

1-6. Background. In the aftermath of Hurricane Katrina in 2005, a study by the "Interagency Performance Evaluation Taskforce" (IPET 2007) found a number of project elevation and reference datum issues that had Corps-wide impact. Subsequent Corps-wide reviews revealed that flood protection and water control structure elevation grades were often referenced to uncertain or superseded terrestrial-based geodetic vertical datums instead of hydraulic/water-level referenced datums from which the structural protective elevations were designed. In some cases, long-term land subsidence, seasonal tidal fluctuations, and sea level change were not always fully compensated for in flood protection structure design or periodically monitored after construction. In addition, navigation projects in tidal regions were often defined to a vertical reference datum that was not based on the latest tidal model for the region, or were defined relative to a datum that was inconsistent with recognized national or international maritime datums. The technical variations and uncertainties between geodetic, satellite-based (ellipsoidal), and water level datums, and their proper application on engineering and construction projects, were often misunderstood.

a. Datum uncertainty impacts. The IPET study found that inadequate or uncertain geodetic and water level datums can lead to the design and construction of deficient flood protection structures. In areas experiencing subsidence or post-glacial rebound, the relationship between the water surface and the project structures changes through time. In coastal districts, sea level change adds to the dynamic nature of this relationship. Reference datum relationships and elevation uncertainties must be factored into the overall risk analysis and design of flood protection structures and navigation project grades. The hydraulic and geodetic elevation relationships must be verified during construction, and periodically monitored after construction to account for subsidence, settlement, periodic nation-wide reference datum redefinitions and readjustments, sea level change, and other factors.

b. Relationships between hydraulic and geodetic datums. Establishing a solid relationship between hydraulic/tidal datums and geodetic datums is critical in relating measurements of wave heights and water level elevations, high-resolution hydrodynamic conditions, water elevations of hydrostatic forces and loadings at levees and floodwalls, elevations of pump station inverts, and related elevations of flood inundation models deriving drainage volumes or first-floor elevations in residential areas. This is best illustrated by the following excerpt from a report "*A National Vertical Datum Transformation Tool*" (Parker 2003).

> *"... the land-water interface depends on how water levels change in both space and time. To combine or compare coastal elevations (heights and depths) from diverse sources, they must be referenced to the same vertical datum as a common framework. Using inconsistent datums can cause artificial discontinuities that become acutely problematic when producing maps at the accuracy that is critically needed by Federal, state, and local authorities to make informed decisions."*

The relationship between the geodetic and hydraulic datums may or may not be easily defined. More often than not, the relationship is complex and requires field survey observations or extensive modeling to quantify. These relationships are especially critical on coastal hurricane protection and navigation projects where accurate hydrodynamic tidal modeling is essential in relating water level elevations to a datum that varies spatially and is time varying due to subsidence or sea level changes. Datums in other parts of the country may be subject to post-glacial rebound. Thus, there is no consistent, non-varying, vertical datum framework for many areas—periodic survey updates and continuous monitoring are required for projects experiencing vertical reference variations.

c. Flood mapping studies. The requirement for accurate vertical datums is emphasized in a National Research Council study "*Mapping the Zone—Improving Flood Map Accuracy*" (NRC 2009). This report concluded that "... the accuracy of elevation data has an enormous impact on the accuracy of flood maps. Ensuring that future flood studies are based on the most accurate and consistent foundation possible requires (1) continuation of a suite of agency elevation programs and (2) acquisition of accurate, high-resolution elevation data." The NRC study found that "... the greatest effect by far of any variant on the BFE [Base Flood Elevation] is from the input data for land surface elevation ... [and that] the base flood elevation profile is significantly more influenced by whether the National Elevation Dataset or LIDAR terrain data are used to define land surface elevation than by any variation of methods for calculating channel hydraulics." A 2009 FEMA report to Congress "*Risk Mapping, Assessment, and Planning (Risk MAP) Multi-Year Plan: Fiscal Years 2010-2014*" (FEMA 2009) outlined that agency's plan for enhancing and maintaining the quality of flood hazard data and flood maps, with particular emphasis on expanded use of LIDAR technology to measure accurately referenced elevations in flood hazard areas.

1-7. Scope of Manual. Chapter 2 provides an overview of geodetic, hydraulic, and tidal datums used to define grades on USACE civil works projects, in both CONUS and OCONUS regions. Chapter 3 contains recommended survey procedures and accuracy standards for referencing project grades to federal frameworks. The remaining chapters (4 through 9) contain detailed guidance for referencing datums on specific types of civil works projects. The appendices to this manual contain application examples of civil works projects that have been adequately referenced to the federal datum frameworks.

1-8. General Background on the Definition and Use of Vertical Datums. Vertical datums typically represent a terrestrial or earth-based surface to which geospatial coordinates (such as heights, elevations, or depths) of project grades are referenced. The vertical datum is the base foundation for nearly all civil and military design, engineering, and construction projects in USACE—especially those civil projects that interface with water.

a. USACE vertical datums. In general, there are five types of vertical datums that are used to reference grades on USACE civil works projects.

(1) Geodetic (or Orthometric) Datums (e.g., North American Vertical Datum of 1988—NAVD88, National Geodetic Vertical Datum of 1929—NGVD29)

(2) Hydraulic Datums (e.g., Low Water Reference Planes—LWRP, IGLD, Pool stages)

(3) Tidal Datums (e.g., Mean Sea Level-MSL, Local Mean Sea Level-LMSL, Mean Lower Low Water-MLLW, Mean High Water-MHW)

(4) Local or Legacy Datums (e.g., Mean Low Gulf-MLG, Chicago City Datum, Memphis Datum, Cairo Datum, local river gage stage, US Engineer Datum-USED, COEMLW)

(5) Global Navigation Satellite System (GNSS) Earth-Centered Datums (e.g., GRS80, WSG84)

b. Multiple datums. Most USACE projects interfacing with water are referenced to at least two of the above datums. Some may require reference to all five. Increasing emphasis and eventual dependence on GNSS satellite positioning for primary construction stakeout and machine control will necessitate that all projects be eventually referenced to satellite-based datums, resulting in a minimum of three reference datums for most projects. Given these multiple reference datums, it is critical that the relationship among the datums be firmly established, maintained, and well documented.

c. Legacy or local datums. Many USACE navigation, flood protection, and water control projects are still referenced to superseded datums, such as Mean Low Water, Mean Sea Level, NGVD29, Sea Level Datum of 1929 (SLD29), etc. Projects referenced to these superseded or legacy datums are, in effect, actually referenced to a "Local Datum." The relationship between this legacy datum, the current federal orthometric datum, and the local hydraulic reference plane is often highly uncertain. Projects referenced to legacy datums must, at minimum, be related to the current federal orthometric or tidal datum. This does not preclude the continued use of these legacy datums for navigation, flood risk management, or water control purposes; only that the relationship between the legacy datum and the current federal datum is established, documented, and maintained.

(1) Local navigation project datums. Navigation projects are usually referenced to an established low water reference plane—a tidal low water on coastal projects and a hydraulic-based reference plane on rivers, pools, lakes, and reservoirs. Tidal navigation project grades that were constructed and maintained to an older local low water datum may need to be updated for subsequent sea level or subsidence changes that have occurred since the project was authorized and/or the legacy datum was established. The current relationship between the legacy datum and the current federal tidal reference datum must be clearly indicated on all project documents.

(2) OCONUS local orthometric datums. NAVD88 or NGVD29 is not applicable to OCONUS projects in the Pacific Ocean region, the Caribbean, and in portions of Alaska where established local datums have been defined by NOAA, USACE, or another agency.

d. Project life-cycle variations in datums. The relationship within and between the reference datums listed above often may be complex given they can deviate spatially over a region, due to a variety of reasons. They may also have temporal deviations due to land subsidence or uplift, sea level changes, crustal/plate motion, project reconstruction, periodic readjustments to the datum origin, or to redefined points on the reference surface. Figure 1-1 illustrates the time-dependent datum variations that may be encountered during the life cycle of a project—in this case a hurricane protection project. It also illustrates the uncertainties and risk assessment factors associated with reference datums that must be considered in designing protection elevations over the life cycle of a project.

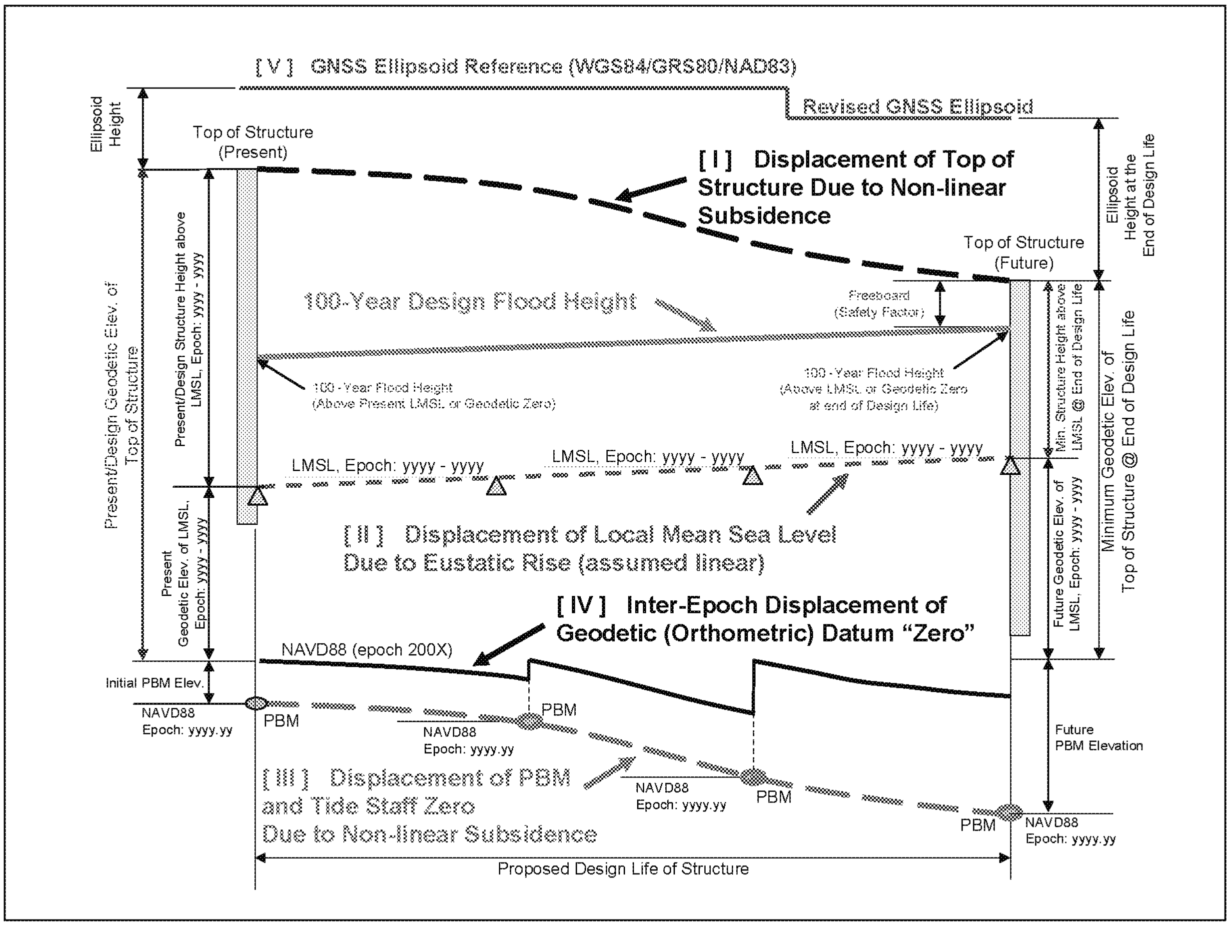


Figure 1-1. Structure design and protection height considerations and uncertainties due to vertical reference datum variations over the life cycle of a project.

(1) In Figure 1-1, the absolute protection elevation of the top of the floodwall is lessened over the project's design life cycle due to local land subsidence [I]. This subsidence is independent of any structure settlement. In addition, apparent (or local) sea level change [II] results in a change of protection, in this example, a loss due to apparent sea level rise. Concurrently, the local reference permanent bench mark(s) (PBM) used to establish constructed grades on the structure, and tide gage reference PBMs used to measure MSL, may be subsiding differently from the structure [III]. In addition, NOAA may make periodic adjustments to the geodetic reference datum [IV], the tidal MSL reference datum [II], or even redefine the datums at some point in the future. The reference ellipsoid datum [V] for satellite GNSS (e.g., GRS80 and WGS84) could also be revised at some point in the future.

(2) Of critical importance in Figure 1-1 is the relationship between the local water surface [II] and the local geodetic reference datum [IV]. This changing relationship must be monitored throughout the life cycle of a project (e.g., 50 + years). Protection elevations are referenced to the local water surface level (e.g., Local Mean Sea Level—LMSL, which in Figure 1-1 is shown rising). The current geodetic reference datum—NAVD88 [IV]—is not based on the design water surface nor is it related to the water surface—it is, in effect, an arbitrary reference system. However, this geodetic datum is used for site plan mapping during design, construction stake out

and grading, and flood plain mapping and related hydrological studies (e.g., resultant Flood Insurance Rate Maps—FIRMS). Future vertical reference datums are proposed on or after 2018 that will align with the gravity/geoid surface and may best fit to hydraulic-dynamic based surfaces.

e. Coastal and inland navigation project references. Referenced depths of navigation projects must likewise have a firmly established relationship between the water surface datum and the geodetic datum. On coastal navigation projects, the reference datum (e.g., Mean Lower Low Water) varies temporally as does Local Mean Sea Level [II] shown in Figure 1-1. It also varies spatially due to the dynamics of tidal ranges in a region, and therefore must be modeled. The modeled MLLW reference plane defines constructed and maintained dredging grades and must be continuously updated for tidal epoch, sea level, and subsidence changes as illustrated in Figure 1-1. On inland navigation projects, the reference datum is normally defined relative to hydraulic parameters (e.g., stages) at local river or pool gages. The geodetic datum is not based on the hydraulic water surface profile; therefore, the relationship between the hydraulic river stages and the geodetic datum must be developed and maintained.

f. Inland flood risk management and water control projects. Elevations of inland flood and water control structures (levees, dams, floodwalls, etc.) are designed, constructed, and maintained relative to hydrologic and hydraulic gage data in the project area. Flow profiles and other computed data from river gages may be referenced to various datums, as shown in Figure 1-2. Computed or modeled flood stage profiles may be referenced to the gage reference zero, the low water reference plane, and/or one of the geodetic datums shown in the figure. The geodetic and satellite reference datums vary spatially between the gages (i.e., they are non-parallel) and contain uncertainties that factor in to the overall uncertainty of a computed flood stage; and thus into the uncertainty and risk analysis estimates of the protection elevation of an adjacent levee, floodwall, or dam—reference ER 1105-2-101 (*Risk Analysis for Flood Damage Reduction Studies*). Figure 1-3 illustrates the elevation uncertainties on a flood protection structure resulting from propagated errors in both reference datums and survey connections. Accurate modeling of water surface profiles on a river system depends (in part) on having a consistent reference datum at the primary gages. Chapters 3 and 6 provide survey procedures and standards for connecting these various reference datums on flood risk management and water control projects. Estimated datum uncertainties are outlined in Chapter 9.

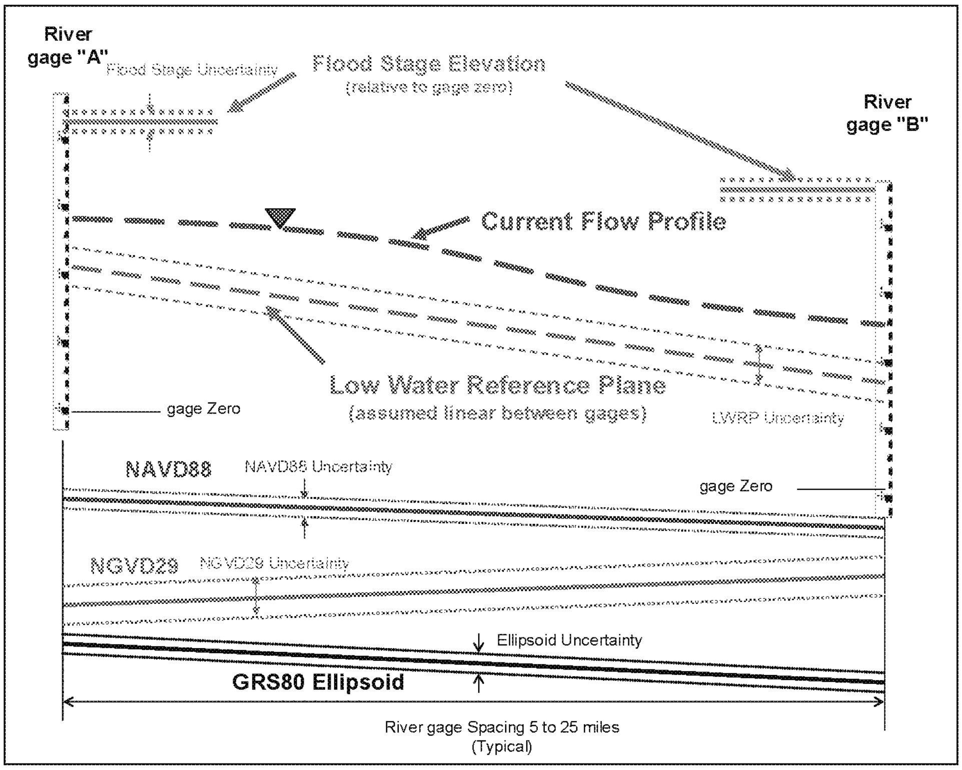


Figure 1-2. Design and protection height considerations and uncertainties due to vertical reference datum variations at gages on an inland river system. (Not to scale)

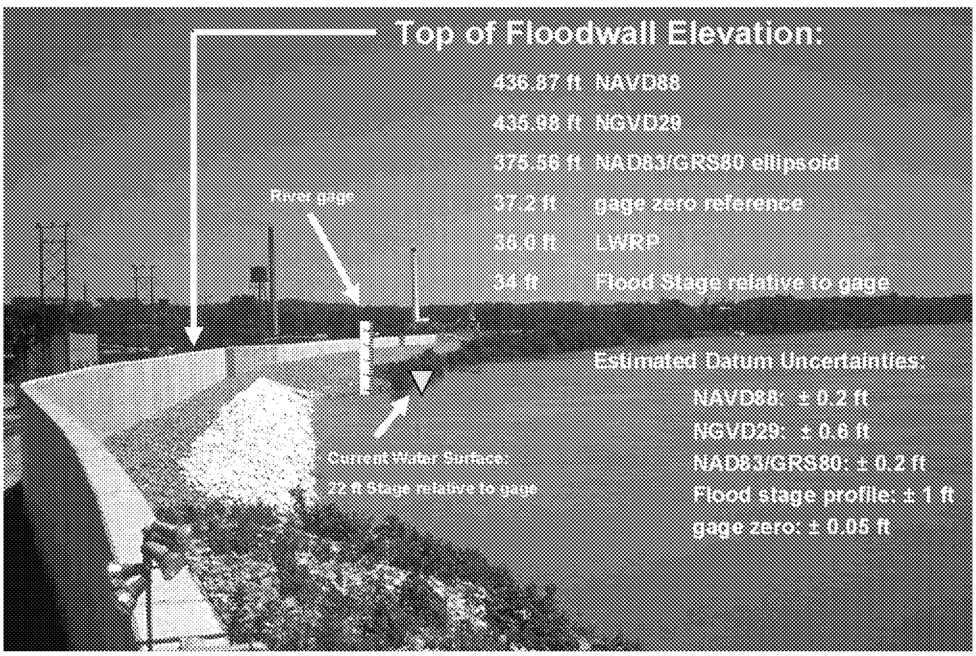


Figure 1-3. Datum and elevation uncertainties on an inland river system floodwall protection height. The reference datum uncertainties propagate to an uncertainty in the floodwall elevation. (see Chapter 9).

1-9. Federal Framework Systems for Referencing USACE Project Grades. It is important that USACE project control and elevation grades conform to the following federal framework systems and guidelines.

a. National Spatial Reference System (NSRS). The NSRS represents an independent framework system for long-term monitoring of the stability of project grades and flood protection elevations. This reference system is maintained by the NOAA National Geodetic Survey (NGS). In addition to USACE, this reference system has been adopted by most Federal agencies, including FEMA, USGS, EPA, and by most state transportation departments (DOT). The NSRS is a national reference framework that specifies latitude, longitude, height (elevation), scale, gravity, and orientation throughout CONUS and most civil works OCONUS locations. It is also the base reference for most GNSS observations. Accordingly, USACE must ensure flood risk management projects and navigation projects are referenced to this NSRS system. This insures consistency in reporting elevations or grades between agencies. In addition, incorporating Corps project control into the NSRS minimizes the need for maintaining independent databases at each District. It also ensures that Corps project control will be automatically updated when future updates to the NSRS are made. Permanent bench marks (PBM), or "*Primary Project Control Points*" (PPCP), on USACE projects shall be firmly connected to the NSRS and submitted to the NGS for inclusion in the published NSRS. Details on these procedures are explained in
Chapter 3.

b. National Water Level Observation Network (NWLON). The NWLON is composed of the continuously operating long-term primary and secondary control tide stations established by the Center for Operational Oceanographic Products and Services (CO-OPS), an agency under the NOAA National Ocean Service. This network provides the basic foundation for the determination of tidal datums for coastal and marine boundaries and for chart datums in CONUS and OCONUS regions. The National Water Level Program (NWLP), also administered by the NOAA CO-OPS, includes the NWLON and water level elevation data and bench mark elevation data from historical long-term and short-term gages operated by that agency. NOAA tidal data are referenced to a specific National Tidal Datum Epoch (NTDE). The specific 19-year NTDE period adopted by NOAA is the official time segment over which tide observations are taken and reduced to obtain mean values (e.g., Mean Sea Level, Mean Lower Low Water, etc.) for tidal datums. A common period of observation is necessary because of periodic and apparent secular trends in sea level. Special NTDEs are adopted for local areas with extreme relative sea level change due to significant land subsidence (e.g., Louisiana) or land rebound (e.g., SE Alaska). CO-OPS computes special NTDEs based on recent 5-year modified tidal datum epochs.

c. FEMA National Flood Insurance Program (NFIP) Guidelines. FEMA has issued a number of publications dealing with flood mapping accuracy standards and related elevation datums that are needed for NFIP studies and to certify or accredit levee/floodwall systems. These certifications are referenced to Base Flood Elevations (BFE) shown on Flood Insurance Rate Maps (FIRMs). Design and constructed elevations on floodwalls, and related freeboard allowances, stillwater elevations, etc. must be consistent with the same regional vertical datums specified in NFIP regulations and guidelines—see "*Identification and Mapping of Special Hazard Areas*" (44 CFR 65) and FEMA's "*Guidelines and Specifications for Flood Hazard*

Mapping Partners" (FEMA 2003). FEMA Elevation Certificates require vertical datum designations for FIRM Base Flood Elevations and building first-floor elevations. Metadata associated with the origin of the datum (reference bench marks, FIRM, etc.) are critical in order to reliably relate FEMA BFEs to USACE floodwall protection elevations.

1-10. Implementation Actions. In accordance with ER 1110-2-8160, USACE commands need to ensure all project grade elevations or navigation depths are referenced directly or indirectly to the NSRS or NWLON framework systems described above. All newly authorized and existing projects should be evaluated to ensure that designed and constructed grades are adequately connected and referenced to the NSRS and the applicable tidal or hydraulic network. The hydraulic/tidal and geodetic vertical datum relationships must be assessed, developed and/or verified during the Feasibility and Preconstruction Engineering and Design (PED) phases, during construction, and periodically monitored after construction to account for subsidence, settlement, NOAA reference datum redefinitions and readjustments, sea level change, and other factors.

a. Critical project datum assessment items. Special attention should be made to assess the following critical issues associated with a project's vertical reference:

(1) Primary project control point bench marks. All projects shall have one or more permanent bench marks—i.e., a PPCP—that is directly connected to and published in the NOAA/NGS National Spatial Reference System (NSRS) network.

(2) Water level gage references. Permanent bench marks used to reference river, pool, reservoir, and tide gages shall be connected to and published in the NOAA National Spatial Reference System (NSRS) network.

(3) Protection grade elevations. Flood/hurricane protection structures and water control structure crest elevations shall be referenced to hydraulic flow or NWLON tidal models that are based on reliable water-level gage data that is referenced to the NSRS and reflects adjustments for sea level, settlement, or subsidence/uplift changes.

(4) Coastal navigation project grades. Coastal navigation project depths shall be defined relative to a local Mean Lower Low Water (MLLW) datum defined by the Department of Commerce; as required by Section 224 of the Water Resources Development Act of 1992 (WRDA 1992). This navigation reference datum shall be based on the latest tidal epoch. Depth measurements shall be spatially corrected based on hydrodynamic tidal models developed from and calibrated to up-to-date water-level gage data, and that field survey techniques are adequately compensating for short-term phase and slope variations in the water surface.

b. Corrective actions. Existing projects deemed deficient in any of the criteria outlined above will require corrective field survey actions. The amount of time and expense will vary considerably, depending on the geographical size of the project, risk assessments, the density and reliability of existing water level gages, and various other factors. Project engineers or managers should prepare a cost estimate in sufficient detail to allow programming the corrective action into the next budget cycle for the project. The guidance listed below synopsizes the effort required for various project conditions.

c. Geodetic control survey connections to the NSRS. At least one PPCP on every project must be geodetically connected to the NSRS. A variety of techniques for performing this connection are described in Chapter 3. In most cases, existing NSRS control in the region will suffice, and no significant field survey effort is required. In nearly all cases, PPCPs can be economically accomplished using Differential Global Positing System (DGPS) height transfer methods relative to the NSRS. Conventional differential leveling may be a more economical option, especially over short distances. PPCPs established or reestablished shall be submitted to NGS for inclusion in the NSRS.

d. Water level gage connections to the NSRS. Water level gages that are used to reference elevations of flood risk management, water control, or tidal parameters on navigation, water control, or HSPP projects must be referenced to and documented in the NSRS. A bench mark referenced to each gage shall be surveyed and placed into the NSRS and continuously maintained in that file. In some cases, this gage reference bench mark may serve as the PPCP for the entire project. Additional details are found in Chapter 4.

e. Coastal navigation project reference datums. Navigation projects in tidal areas that were not adequately updated to a current MLLW reference datum, or have outdated or unknown origin tidal modeling regimes (phase and range), or are on superseded tidal epochs, will require field efforts to update the project. This may require setting one or more short-term tidal gages to perform simultaneous comparison datum translations between an existing NWLON station and/or developing a tidal model utilizing NOAA hydrodynamic modeling techniques which can be applied to develop the MLLW datum relationship over a project reach. Minimizing tidal phase errors may require mandated utilization of GNSS differential carrier phase water surface elevation measurements in lieu of extrapolated gage elevations—i.e., Real Time Network (RTN) applications such as Real Time Kinematic (RTK), Virtual Reference Networks (VRN), or Virtual Reference Stations (VRS). Details on these methods are covered in Chapter 4.

f. Coastal navigation or Hurricane and Shore Protection Projects (HSPP) projects on non-standard or undefined tidal datums. Projects on antiquated or non-standard tidal datums must be converted or related to the MLLW datum established by NOAA used for coastal navigation and maritime charting in CONUS or OCONUS waters. This includes those projects that are still referenced to legacy datums such as Mean Low Water (MLW), Mean Gulf Level (MGL), Mean Low Gulf (MLG), Gulf Coast Low Water Datum, Old Cairo Datum 1871, Delta Survey Datum 1858, New Cairo Datum 1910, Mean Tide Level, Corps of Engineers Mean Low Water (COEMLW), U.S. Engineer Datum (USED), etc.

g. Mean Sea Level (MSL) or NGVD datums. Project control elevations or bench marks defined generically to "Mean Sea Level" or "NGVD" without any definitive source data (metadata) probably have no firmly established relationship to the current NSRS and may need to be resurveyed. "NGVD29" was once known as the "Sea Level Datum of 1929." However, neither NGVD29 nor the current NAVD88 datums are equivalent to "mean sea level." Resurveying will entail establishing a hydraulic and a NSRS geodetic reference, as applicable. Details are outlined in Chapter 3.

h. Permanent bench mark control requirements for extensive flood risk management or reservoir projects. Levee projects encompassing large geographic extents may require more than one PPCP to cover the project area. PPCPs should be added as necessary to control the project grades and features using conventional surveying methods, or preferably at a sparser density needed to accommodate GPS real-time kinematic construction survey or machine control methods. These permanent bench marks must be firmly connected to applicable hydraulic gages and regional NSRS datums as described above, and, where required, should be submitted to NGS for inclusion into the NSRS. Requirements for additional NSRS densification on large flood risk management or water control reservoir projects are covered in Chapter 6.

i. Projects subject to high subsidence rates. Projects located in high subsidence areas (e.g., portions of Louisiana, Texas, and California) may require special attention. This also applies to areas on the Northwest coast (e.g., Alaska) and other locations that may be subject to crustal uplift or glacial rebound. Vertical elevations of reference bench marks, water level gages, and protection structures must be continuously monitored for movement and loss of protection. This monitoring can be accomplished using static GPS survey methods or conventional differential leveling. In high subsidence areas, independent local vertical control networks referenced to the NSRS may be established for these purposes. These vertical networks are periodically resurveyed at intervals dependent on subsidence rates. For example, in the New Orleans, LA area, primary control PBMs on these monitoring networks are date-stamped to signify reobservation/readjustment epochs—e.g., "BM XYZ (2004.65)." Additional technical guidance for monitoring subsidence or uplift can be obtained from the USACE Army Geospatial Center (AGC) and the NGS. Details are covered in Chapter 8.

j. Ecosystem restoration projects. In aquatic ecosystem restoration projects, the appropriate vertical datum should be taken into consideration during all project phases. Restoration projects should be based on valid water level measurements, and in some cases, the current NSRS geodetic datum. Often vertical datums for restoration projects need to establish the relationship between historical and current water level and geodetic datums to ensure the ecosystem restoration success. For ecosystem restoration projects in coastal areas, see Chapter 5 for details in defining the appropriate water level datum. See Chapter 6 for details in defining the appropriate datum to be used for non-coastal ecosystem restoration projects.

k. Regulatory permitting actions. Compensatory mitigation projects or regulatory permitting activities that are referenced to tidal or non-tidal datums should be defined to an established datum based on valid water level observations, as appropriate to local, state, and federal statutory requirements. Statutory Mean High Water (MHW), High Tide Line (HTL), etc. boundary demarcations in coastal areas may, in some cases, require direct reference to NOAA NWLON gage networks. Refer to details in Chapter 7.

1-11. <u>Periodic Reassessments of Controlling Reference Elevations</u>. Periodic reevaluations of project reference elevations and related datums covered in this manual should be included as an integral component in the various civil works inspection programs of completed projects. The frequency that these reevaluations will be needed is a function of estimated magnitude of geophysical changes that could impact flood protection or navigation grades. Project elevations and dredging grades that are referenced to tidal datums will have to be periodically coordinated with and/or reviewed by NOAA to ensure the latest tidal hydraulic effects are incorporated and that the project is reliably connected with the NSRS. In all cases, a complete reevaluation of the vertical datum should be conducted at each scheduled periodic inspection. Shallow-draft navigation projects may have different criteria. Any uncertainties in protection levels that are identified during the inspection will also need to be incorporated into any applicable risk/reliability models developed for the project—see EM 1110-2-1619 (*Risk Based Analysis for Flood Damage Reduction Studies*).

1-12. Metrics and Accuracy Definitions. Both English and metric units are used in this manual. Elevations, depths, and gage data for USACE civil works projects are expressed in English units, following local engineering and construction practices. Exceptions may exist on some OCONUS projects. GNSS observation data and standards are normally in metric units. NOAA geodetic data and water level gage data are published in English and/or metric units. Satellite-derived geographical or Cartesian coordinates are transformed to English units for use in local project reference and design systems, such as State Plane Coordinate System (SPCS) grids or local construction chainage-offset systems. English/metric equivalencies are noted where applicable, including the critical—and often statutory—distinction between the US Survey Foot (1,200/3,937 meters (m) exactly) and International Foot (30.48/100 m exactly) conversions. One-dimensional (1D), two-dimensional (2D), and three-dimensional (3D) accuracy or uncertainty statistics, standards, and tolerances specified in this manual are defined at the 95% RMS confidence level. Cost estimates cited in this manual are in 2010 dollars.

1-13. Trade Name Exclusions. The citation or illustration in this manual of trade names of commercially available products, including supporting surveying equipment, instrumentation, and software, does not constitute official endorsement or approval of the use of such products.

1-14. Abbreviations and Acronyms. Abbreviations and acronyms used in this manual are listed in the Glossary.

1-15. Manual Development, Technical Assistance, and Training. Technical guidance in this manual was developed by the Army Geospatial Center (AGC) in conjunction with the U.S. Army Engineer Research and Development Center (ERDC) Coastal and Hydraulics Laboratory (CHL), the NOAA National Geodetic Survey (NGS), the NOAA Coast Survey Development Laboratory (CSDL), and the NOAA Center for Operational Oceanographic Products and Services (CO-OPS). The AGC (National Datums and Subsidence Program) may be contacted for detailed technical guidance and formal training in evaluating the adequacy of existing project reference datums and survey techniques needed to connect project control with the NSRS. Reference http://www.agc.army.mil/ndsp.

1-16. Proponency and Waivers. The HQUSACE proponent for this manual is the Engineering & Construction Community of Practice. Waivers to this guidance should be forwarded through MSC to HQUSACE (ATTN: CECW-CE).

CHAPTER 2

Geodetic, Tidal, and Hydraulic Reference Datums Used to Define Project Grades on Civil Works Projects

2-1. Purpose. This chapter provides a technical overview of the interrelationship between geodetic (i.e., orthometric) and hydraulic datums that are used to reference various civil works projects. These datums are the baseline reference for designing protection elevations of levees and related water control structures, and the design depths of navigation projects. They are also used for setting grades during project construction and maintenance operations. The Corps uses a variety of orthometric and water level datums to reference coastal and inland navigation projects. Figure 2-1 provides a generalized illustration of the various references used on coastal and inland navigation projects in tidal, free flow, and controlled regimes. These same orthometric and hydraulic datums are also used to reference elevations of inland levees and dams.

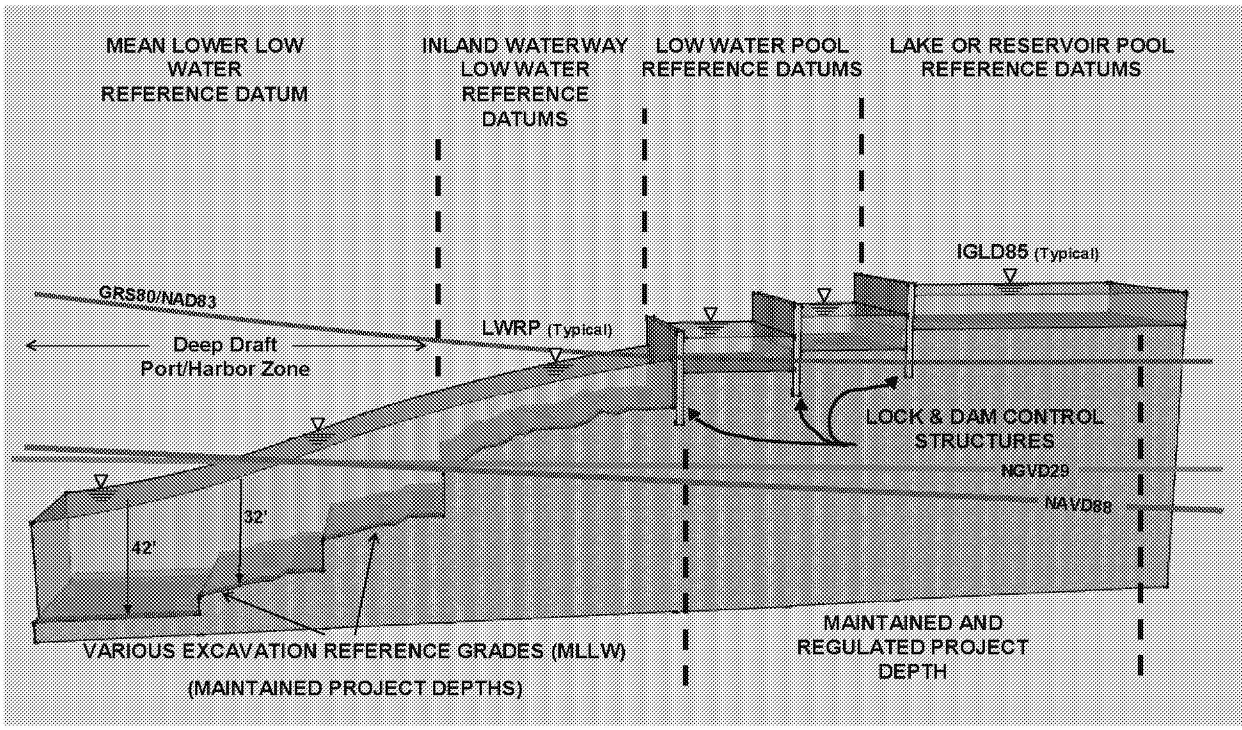


Figure 2-1. Tidal and inland vertical reference datums.

2-2. Geodetic and Hydraulic Vertical Reference Systems. The following paragraphs provide a general overview of the types of vertical datums used to define the elevations of USACE flood risk management, water control, HSPP, and navigation projects. Appendix B provides additional information on terrestrial and extraterrestrial geodetic datums and related 2D and 3D coordinate systems. For a more comprehensive discussion on geodesy, vertical datums, and GNSS height measurement, refer to the following publications: "*Physical Geodesy*" (Hofmann 2006) or "*What Does Height Really Mean*" (Meyer 2006).

a. Definition of geodetic datum. The "*Geodetic Glossary*" (NGS 1986) defines a geodetic datum as:

"*A set of constants specifying the coordinate system used for geodetic control, i.e., for calculating the coordinates of points on the Earth.*"

(1) The above general definition applies to both horizontal and vertical datums. Vertical datums are normally defined relative to the fixed elevation of some point(s) on the Earth, or in the case of satellite-based ellipsoidal reference systems, a three-dimensional coordinate of a point near the mass center of the Earth.

(2) A more comprehensive definition of vertical datums that directly relates to studies of coastal and inland flooding, and USACE flood risk management project elevations, is outlined in the following excerpts from "*Mapping the Zone: Improving Flood Map Accuracy*" (NRC 2009):

"The data components of a flood study that involve a measurement of height or elevation can be grouped into four general categories:

(a) Elevation reference surface. Before elevation can be measured or the data used in engineering analysis, a measurement system must be established. The location of "zero" and a physical reference for elevation zero (in other words, a vertical datum) must be established on the Earth, where it can be used for all types of height measurements.

(b) Base surface elevation. Two types of base surfaces are important to flood studies: land surface elevation (topography) and its underwater equivalent (bathymetry). Topography is expressed as the height of a location above the geodetic datum and is in most cases a positive value. Bathymetry is expressed as the depth of the land surface below rivers, lakes, and oceans; positive depth is equivalent to negative elevation.

(c) Water surface elevation. The depth of water in rivers, lakes, and streams and the point at which water overtops their banks and spreads across the landscape are the subjects of riverine flood studies. The depth of water in the ocean and the impact of extreme events such as hurricane-induced storm surge or earthquake-induced tsunamis are the subjects of coastal flood studies. The height of water surfaces is measured with stream and tide gages. The location and elevation of the gages themselves must be determined accurately in order to correctly relate water surface measurements to other elevations.

(d) Structure elevation. The vulnerability of buildings and infrastructure to flood damage is directly related to their location with respect to the floodplain and the elevation and orientation of critical structural components with respect to the height of potential floodwaters. In addition, structures within the floodway (such as bridges, dams, levees, and culverts) influence the conveyance of water in a stream channel during a flood event, affecting flood heights."

b. Orthometric elevations and vertical datums. Floodwall and levee protection heights (and related inundation mapping elevations) are normally referenced to "orthometric" vertical datums established by the National Geodetic Survey. Orthometric vertical datums provide a design and construction framework for referencing tidal gages and hydraulic models over a region. Orthometric datums are based on geopotential or equipotential surfaces referenced to some defined terrestrial origin—e.g., a tide gage PBM or the geoid. The two major orthometric datums used in CONUS include:

(1) National Geodetic Vertical Datum of 1929 (NGVD29)—superseded in the early 1990s.

(2) National Geodetic Vertical Datum of 1988 (NAVD88).

Older water control projects may be referenced to superseded vertical datums—e.g., MSL 1912. NAVD88 is the current federally recognized elevation reference system throughout CONUS. Neither NGVD29 nor NAVD88 are true "sea level datums." They are not equivalent to "Local Mean Sea Level" in CONUS. For example on the West Coast, NAVD88 is about 3 ft below LMSL. Failure to account for these orthometric datum anomalies in the design of a floodwall elevation can have significant adverse consequences since orthometric height differences in NAVD88 only approximate actual energy head differences. A redefinition of the NAVD88 is anticipated on or after 2018. This revision using gravity observations is expected to better approximate actual dynamic head elevation differences.

c. Hydraulic datums. These datums are found on inland river, lake, or reservoir systems, typically based on a low water pool or discharge reference point. Examples are the Mississippi River Low Water Reference Plane (e.g., LWRP74, LWRP93, or LWRP07) and the International Great Lakes Datum (IGLD55 or IGLD85). Low water reference planes may be defined relative to 97% discharge flows at river gages, from which river stage elevations are derived. River gage stage elevations are usually referenced to an orthometric datum such as NGVD29 or NAVD88. Hydraulic-based datums in inland waterways directly reference flood profiles and related elevations of flood protection levees or floodwalls and navigation clearances. A variety of inland reference planes are used in controlled pools and reservoirs, such as normal pool level, minimum regulated pool level, and flat pool level, low flow regulation pool, seasonal pool, and conservation pool. Dynamic height differences are often used in relating hydraulic datums. Dynamic heights, unlike orthometric heights, represent geopotential energy (hydraulic head) gradients in water surfaces (canals, rivers, lakes, reservoirs, hydropower plants, etc.) and thus may have application to Corps hydraulic models.

d. Tidal datums. Tidal datums are used throughout all USACE coastal areas and are based on long-term water level averages of a phase of the tide. Mean Sea Level (MSL) datum (or more precisely Local Mean Sea Level--LMSL) is commonly used as a base reference for hydrodynamic storm modeling, wind and wave surge modeling, high water mark observations, stillwater surge elevations, and design of coastal hurricane protection structure elevations. The relationship between these water elevations and the orthometric datum elevation varies spatially and must be computed or modeled. Depths of water in coastal navigation projects in the United States are usually defined relative to Mean Lower Low Water (MLLW) datum, but sometimes a local legacy datum is used. In isolated non-tidal coastal areas (e.g., Pamlico Sound, NC and Laguna Madre, TX) NOAA uses a Low Water Datum (LWD) as a chart datum. Tidal datums are essentially local datums (i.e., LMSL) and should not be extended more than a few hundred feet from the defining gage without substantiating measurements or models. It is essential that the vertical datum plane used in these models use the geoid (or other equipotential surface) and not a geometric plane surface. Tidal datums are periodically updated by NOAA and thus are defined by their National Tidal Datum Epoch (NTDE)—currently 1983-2001.

e. Satellite or space-based datums. Satellite datums are three-dimensional, geocentric, ellipsoidal datums used by Global Navigation Satellite Systems (GNSS), such as the Global Positioning System (GPS)—e.g., ITRF and WGS84. The reference point for these systems is the estimated mass center of the earth. Ellipsoid heights of points in CONUS represent elevations relative to the NAD83/GRS80 mathematically defined ellipsoid. These ellipsoid heights can approximately be transformed to a NAVD88 orthometric elevation using a gravity (geoid) model developed by the National Geodetic Survey. This geoid model approximates the current NAVD88 orthometric reference surface in CONUS.

f. Local or legacy datums. Most USACE civil projects are, in effect, referenced to a local vertical datum. Nearly all construction, boundary, and real estate surveys are aligned to local horizontal datums, e.g., section corners, property corners, road intersections, chainage-offset construction layout, etc. Many local datums are based on arbitrary, unknown, or perhaps archaic origins. Vertical construction datums are often referenced to an arbitrary elevation at a PBM (e.g., elevation 100.00 ft). Some local datums with designated origins may be at distant points from a project—e.g., New Cairo Datum (Cairo, Illinois) projected south to the Gulf Coast in Louisiana. Most hydraulic-based river datums and MSL/MLLW tidal datums are actually local datums when they are not properly modeled or kept updated. Other local or legacy datums encountered in USACE may include Mean Low Gulf (MLG), Mean Gulf Level (MGL), Mean Low Tide (MLT), Old/New Memphis Datums, and Delta Survey Datum. USACE PBMs, TBMs, and floodwall elevations referenced to NGVD29 must be considered a local datum in that relationships to the national NSRS network are no longer maintained. Height differences between points determined from differential leveling are effectively local datums unless orthometric or dynamic height corrections are applied to the observed elevation differences. Geospatial coordinates for such points are primarily used for external reference, such as GIS mapping.

2-3. Background on the Definition of the National Geodetic Vertical Datum of 1929 (NGVD29). Since 1929, only two official national vertical datums have been established—NGVD29 and NAVD88. Prior to 1929, the reference surface for a vertical datum has been some approximation of local mean sea level, but this was not a strict requirement. By 1900, the vertical control network for the United States had grown to 21,095 km of geodetic leveling. A reference surface was determined in 1900 by holding elevations referenced to local mean sea level (LMSL) fixed at five tide stations. Data from two other tide stations indirectly influenced the determination of the reference surface. Subsequent readjustments of the leveling network were performed by the US Coast and Geodetic Survey (USC&GS) in 1903, 1907, and 1912.

a. The first of these national datums was the Sea Level Datum of 1929 (SLD29). SLD29 was created by the US Coast and Geodetic Survey (USC&GS) as the datum to adjust all vertical control to in North America. The SLD29 is defined by 26 tide stations (held fixed to Local Mean Sea Level)—21 tide stations in the United States and five tide stations in Canada. When it was established in 1929, SLD29 was believed to be a "mean sea level" datum although mean sea level was not the same at each gage. Mean sea level was not developed using the same epoch or period of record at each of the gages. Each gage was, in effect, a "local mean sea level" (LMSL) reference datum. However, over time, with sea level rise and other factors, it was no longer considered a "mean sea level" datum. In 1973, the name of SLD29 was changed to the National Geodetic Vertical Datum of 1929 (NGVD29).

b. In 1929, the international nature of geodetic networks was well understood, and Canada provided data from its first-order vertical network to combine with the US network. The two networks were connected at 24 locations through vertical control points (bench marks) from Maine/New Brunswick to Washington/British Columbia. Although Canada did not adopt the "Sea Level Datum of 1929" determined by the United States, Canadian-US cooperation in the general adjustment greatly strengthened the 1929 network. Table 2-1 lists the kilometers of leveling involved in the readjustments and the number of tide stations used to establish the datums.

Table 2-1. Legacy Vertical Datums in CONUS. (IPET 2007)

Year of Adjustment	Kilometers of Leveling	Number of Tide Stations
1900	21,095	5
1903	31,789	8
1907	38,359	8
1912	46,468	8
1929	75,159 (U.S.)	21
	31,565 (Canada)	5

c. Holding Local Mean Sea Level (LMSL) heights fixed at these tide stations did not mean that the geodetic vertical datum and the LMSL were the same at any location outside of the 26 tide gages. Immediately after the 1929 adjustment, the relationship between NGVD29 and LMSL began to deviate due to apparent sea level change. NOAA updated LMSL and MLLW datums in the US with every change in National Tidal Datum Epoch (NTDE) starting with 1941-1959, 1960-1978, and 1983-2001. NGVD29 was not adjusted to account for sea level change during this time period. There were several later adjustments to the NGVD29 datum, but no change in the national geodetic datum until 1991, when NGS established the NAVD88. Adjustments to the datum are noted by the year (or epoch) in parentheses after the datum name, i.e., NGVD29 (19xx) where 19xx is the year the NGVD29 datum was readjusted in a region or local area based on either new data or releveling of an existing level line. It is noted that this is only an adjustment of the network and not a new datum.

Additionally, the local mean sea level at each of the 26 gages did not lie on the same equipotential surface due to local factors such as prevailing winds, ocean currents, etc. These differences were introduced into the national network as errors during the network adjustment.

2-4. Background on the Definition of the Current North American Vertical Datum of 1988 (NAVD88). Unlike the multiple points which define the "zero level" of NGVD29, NAVD88 is defined by a single tidal bench mark at Father Point/Rimouski, an International Great Lakes Datum of 1985 (IGLD85) water level station at the mouth of the Lower St. Lawrence River, in Quebec, Canada. Its elevation was held fixed in a minimally constrained, least squares adjustment, which is not distorted by constraints of local mean sea level in different areas, as in NGVD29. The warping of NGVD29's reference surface means that the heights determined in that datum are not strictly "orthometric." Conversely, NAVD88's reference surface is equipotential, and therefore heights in that datum are nearly orthometric. The reason they are not truly orthometric is that the reference surface of NAVD88 was not specifically chosen as the geoid. In fact, most estimates of the difference between the NAVD88 reference surface and the geoid put the difference at the level of a few decimeters.

a. In support of NAVD88, the NGS converted the historic height difference links involved in the 1929 general adjustment to computer-readable form. The 1929 general adjustment was recreated by constraining the heights of the original 26 coastal stations. Free-adjustment results were then compared with the general adjustment constrained results. Several differences exceeded 50 cm. A large relative difference, 86 cm, exists between St. Augustine, Florida, and Fort Stevens, Oregon. This is indicative of the amount of distortion present in the 1929 general adjustment.

b. NAVD 88 combined 1,300,000 kilometers of leveling surveys held in the NGS data base, into a single least squares adjustment to provide users with improved heights for over 500,000 vertical control points distributed throughout the United States, on a common datum. There had been approximately 625,000 km of leveling added to the National Geodetic Reference System (NGRS) since NGVD29 was created. (The NGRS has been superseded by the NSRS). An extensive inventory of the vertical control network resulted in the identification of lost bench marks, several affected by crustal motion associated with earthquake activity, postglacial rebound (uplift), and subsidence. Other problems (distortions in the network) were caused by forcing the 625,000 km of leveling to fit previously determined NGVD29 height values. Some observed changes, amounting to as much as 9 m, were noted.

c. The NAVD88 datum adjustment formally began in October 1977 with releveling much of the first-order NGS vertical control network in the United States. The nature of such a network required a framework of newly observed height differences to obtain realistic, contemporary height values to form the readjustment. To accomplish this, NGS identified 81,500 km (50,600 miles) for releveling to be completed by NGS field crews. In addition to the NGS releveling, other federal agencies such as the USACE, many state agencies such as state Departments of Transportation, Departments of Natural Resources, etc. provided NGS with approximately another 20,000 km (32,400 miles) of new and releveled surveys. Replacement of disturbed and destroyed monuments preceded the actual leveling. This effort also included the establishment of "deep-rod" bench marks, which provided reference points for future "traditional" and GPS leveling techniques. Field leveling of the 81,500 km network, and the 20,000 km submitted by state agencies, was accomplished to Federal Geodetic Control Committee (FGCC) First-Order, Class II specifications, using the "double-simultaneous" method. NGS worked closely with both Canada and Mexico to ensure sufficient connections were made along both borders of the United States. NGS field crews also worked closely with both countries to carry the vertical control into both countries and make connections to their vertical network and both countries ran into the United States making connections. Both Canada and Mexico provided NGS with their leveling data so that the NAVD88 would be more extensively “North American” than NGVD29 had been. The general adjustment of NAVD88 was completed in June 1991.

d. The leveling observations used in NAVD88 were corrected for rod scale and temperature, level collimation, and astronomic, refraction, and magnetic effects. All geopotential differences were generated and validated, using interpolated gravity values based on actual surface gravity data. Geopotential differences were used as observations in the least-squares adjustment, geopotential numbers were solved for as unknowns, and after the adjustment was complete, orthometric heights were computed using the well-known Helmert height reduction. The weight of an observation was calculated as the inverse of the variance of the observation, where the variance of the observation is the square of the a priori standard error multiplied by the kilometers of leveling divided by the number of level sections.

2-5. Satellite-Based Vertical Reference Systems. The current and rapidly expanding use of satellite-based ellipsoidal reference systems provides a mechanism for establishing an external reference framework from which orthometric, tidal, hydraulic, and local vertical datums can be related spatially and temporally. GPS along with other expanding global navigation and positioning systems (i.e., GNSS or Global Navigation Satellite Systems) such as GLONASS (Russian Federation), Galileo (European Community), Compass (China), etc. will further the use of satellite-based systems as the primary measurement reference for project elevations, dredging grades, machine control, and related mapping applications. Various initiatives are underway by NOAA, FEMA, and other agencies to refine the models of some of the various vertical datums listed above—resulting in a consistent National Spatial Reference System that models and/or provides transformations between the orthometric, tidal, and ellipsoidal datums. Paramount in these efforts is the NOAA "National VDatum" project that is designed to provide accurately modeled transformations between ellipsoid-based reference systems, orthometric datums, and tidal datums.

a. NAD83/GRS80 ellipsoid. In the near future, most engineering and construction site control (including GPS/GNSS-based machine control systems) will be referenced using various DGPS/RTN techniques; therefore, it is essential that all USACE project elevations be referenced to the NAD83/GRS80 ellipsoid so that the relationship between this ellipsoidal datum and local hydraulic/tidal datums is firmly established. Most federal agencies, including USACE in EM 1110-1-1003 (*NAVSTAR GPS Surveying*), have specifications for measuring and defining vertical elevations derived from satellite-based measurements.

b Ellipsoid and orthometric heights. In recent years much emphasis has been put on the determination of orthometric heights from GPS ellipsoid height measurements, as shown in

Figure 2-2. In this figure the "plumb line" is the curved line between a point on the earth's surface and a point on the geoid, everywhere tangent to the direction of gravity (or, in other words, everywhere perpendicular to all equipotential surfaces through which the line passes). The "orthometric height" is exactly the distance along this curved plumb line between the geoid and point on the earth's surface. Close approximations can be made, but for absolute accuracy, gravity needs to be measured along this line, requiring a bored hole, which is impractical. For general geodetic control survey applications in USACE, GPS height difference observational accuracy can equal or exceed traditional (leveling) observations. As illustrated in Figure 2-2, with a highly accurate model of the geoid (geoid height—"N"), the purely geometric ellipsoidal height "h" determined by GPS can be transformed into an orthometric height "H"—e.g., NAVD88.

$$h \approx H + N \quad or \quad H \approx h - N \qquad \text{Eq. 2-1}$$

where,

h = Ellipsoid Height (NAD83/NSRSxx)
H = Orthometric Height (NAVD88)
N = Geoid Height (GEOIDxx)

c. Ellipsoid and geoid heights. The ellipsoid surface has nothing to do with the level surfaces and it cuts through all level surfaces because it is not a function of the Earth's gravity field. Therefore GPS-derived ellipsoid heights are not related to the geoid or the gravity field; thus requiring a model to obtain differences between the geoid and ellipsoid to determine orthometric height. Geoid height (also termed geoid separation or geoid undulation) is the difference between the geoid and ellipsoid at any given point on the earth's surface. The geoid height is always negative in CONUS (as shown in Figure 2-2). The term "equipotential surface" is defined as an irregular surface, whose gravity potential energy is constant at every point. By extension, therefore the force of gravity is perpendicular to an equipotential surface at every location on that surface. Because the value of gravity potential energy can be any number (corresponding to one equipotential surface), there are therefore an infinite number of equipotential surfaces surrounding the Earth with each equipotential surface lying either completely within or completely without another surface; they do not intersect one another. Due to the non-homogenous distribution of Earth's masses, each of these surfaces has its own distinct shape.

d. Geoid and local mean sea level. The "geoid" is the one equipotential surface which most closely fits global mean sea level in a least squares sense. However variations between local mean sea level and the geoid at one location may be radically different from such variations at another location. As an example the LMSL-geoid difference in New Orleans is not the same as LMSL-geoid difference in Miami, Florida since the geoid is fit to global mean sea level and its definition is therefore not strongly influenced by the local hydrodynamic phenomena which affect local mean sea level. In the absence of all forces besides gravity, the ocean surface would lie on the geoid. However tides, currents, river runoff, wind, circulation, and other forces all impact sea level. The effects of these forces do not average to zero over time, and since these forces vary from site to site, any given tide gage may determine local mean seal level but not directly determine the geoid. Due to this difference in variations between the geoid and local mean sea level, and the fact that 26 tide stations were held fixed in establishing NGVD29, the NGVD29 reference surface was warped to allow the local mean sea level at tide stations to define the "zero elevation" of heights in the NGVD29 datum; hence, NGVD29's reference surface is not equipotential.

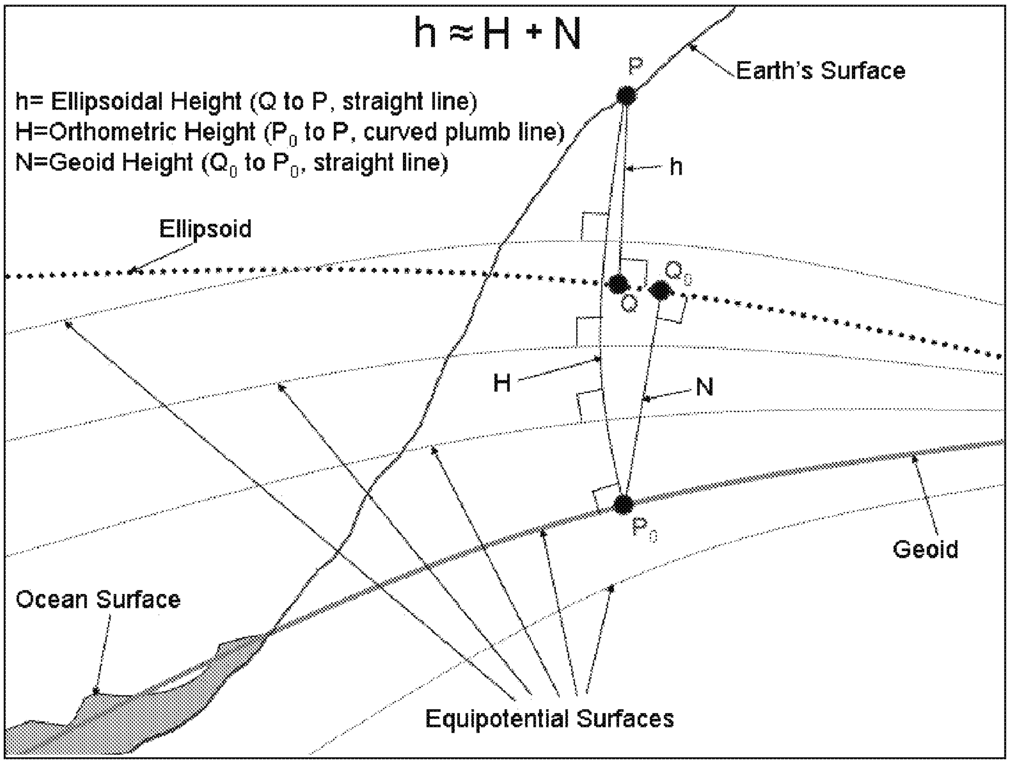


Figure 2-2. Relationship between the ellipsoid, geoid and orthometric heights. (IPET 2007)

e. Satellite height and leveled height differences. Over short distances, satellite derived elevation differences are not as accurate as those that are determined from traditional spirit or digital leveling observations. Therefore, traditional spirit leveling will normally be used for local construction stakeout. Satellite (RTN) observations are acceptable for detailed site plan design.

f. Orthometric height and dynamic height differences. Leveled elevation differences between bench marks do not yield either orthometric height differences or dynamic height differences. Spirit or digital leveling differences in elevation must be corrected to obtain orthometric heights or dynamic heights—i.e., orthometric corrections or dynamic corrections—see Hofmann 2006. Orthometric corrections, being a function of a level line length and direction, are usually negligible for engineering purposes. Dynamic height corrections are usually negligible except in high elevation (energy head) differences, such as those occurring between a hydroelectric power plant's reservoir intake structure and the lower spillway. Due to inaccuracies in NAVD88 leveling adjustments, a "hydraulic corrector" must be applied at subordinate points on the Great Lakes in order to obtain a reference engineering, construction, or navigation datum. These hydraulic correctors are published by the IJC Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data (IJC 1995).

g. GPS/GNSS reference frames. Navigation satellite orbits are computed from data collected by a global network of receivers coordinated by the International GNSS Service for Geodynamics (IGS). The accuracy of the GPS orbits depends on many factors, including the accuracy of the coordinates of the data collection sites. The earth's surface is not fixed and rigid like an eggshell. It consists of many sections, or plates, which move slowly over time in various directions and rates in a process called crustal motion. Scientists have been studying this movement for several reasons. This includes trying to determine where land masses are with respect to one another and where they will be in the future. IGS monitoring sites are located on these crustal plates. The International Earth Rotation Service (IERS) periodically computes the positions of the sites for a given date. The sites define the IERS, the International Terrestrial Reference Frame (ITRF), and the date defines the epoch. The IERS also computes the movement velocities of the sites to estimate where the sites will be in the "near" future with some degree of accuracy. The ITRF is an internationally accepted standard, and is the most accurate geocentric reference system currently available. The longer the sites operate, the better the positions and velocities can be determined and the more accurate the satellite orbits will be.

2-6. Tidal Datums Used to Reference Coastal HSPP and Navigation Projects. Tidal datums are used to establish local tidal phase averages as reference levels from which to reckon flood/hurricane protection structure heights or depth measurements in a navigation project. One of these tidal averages is the mean level of the water surrounding the gage. Observations are taken from a tide gage that has been collecting data for a period covering a 19-year National Tidal Datum Epoch period—NTDE. This time period allows inclusion of all practical variations in the path of the moon about the earth and the earth about the sun. Tidal datums are locally derived and must not be extended into areas that have differing hydrographic characteristics, without substantiating measurements. The most commonly used tidal datums are:

a. Mean Sea Level (MSL) or Local Mean Sea Level (LMSL). The average height of the surface of the sea at a tide station for all stages of the tide, typically covering a 19-year period which is usually determined from hourly height readings measured from a fixed and predetermined reference level. Most USACE coastal hydrodynamic modeling and design is referenced to MSL.

b. Mean Lower Low Water (MLLW). The average height of the lower of the two low waters occurring in a day, at a tide gage over a 19-year period. Most CONUS, and some OCONUS, coastal navigation projects are referred to this datum. This datum superseded Mean Low Water (MLW) that was previously used as the navigation reference datum for the East Coast CONUS. Some HSPP and navigation projects may still be referenced to a legacy MLW datum.

c. Mean High Water (MHW). The average height of all high waters at a tide station, covering a 19-year period. Heights of bridges over navigable waterways and legal coastal shoreline boundaries are referred to this datum. Likewise are legal shoreline boundaries in many jurisdictions (variations of MHW are outlined in Chapter 7). Coastal shorelines shown on navigation charts depict MHW whereas depths on the same chart are referred to Mean Lower Low Water. Exceptions to this are found on USACE inland navigation charts.

d. Mean Tide Level (MTL). Sometimes termed half-tide level, a plane often confused with LMSL that lies close to LMSL. MTL is the midpoint plane exactly between the average of MHW and MLW at a tide station. MTL does not include all the tide levels (i.e., MHHW and MLLW). Hydraulic design manuals sometimes erroneously refer to MTL as being synonymous with Mean Sea Level.

Additional details on these tidal reference planes are covered in Chapters 4 and 7, and in NOAA technical publications listed at Appendix A.

2-7. Geodetic and Hydraulic Datum References on USACE Projects. A variety of vertical reference systems are used on Corps flood protection and navigation projects. Of significance is the local relationship between the terrestrial or orthometric datums (NAVD88) and the hydraulic datums (MSL, LMSL, MLLW, LWRP, Normal Pool, etc.) from which flood protection heights and navigation grades are modeled and designed. During the detailed design or evaluation of flood protection or HSPP projects, outdated or superseded geodetic datums (e.g., NGVD29, MSL 1912) should be referenced to the federal NSRS datum—e.g., NAVD88. Likewise, outdated riverine, pool, reservoir, lake, or tidal reference planes should be referenced to the current NSRS datum.

a. CONUS and OCONUS reference datums. References throughout this guidance to the NSRS (NAVD88) are applicable only to the current vertical adjustment in the CONUS. NOAA has established independent vertical datums (orthometric or tidal) for some OCONUS locations—e.g., Puerto Rico (PRVD02), Guam (GUVD04), US Virgin Islands (St. Thomas--VIVD09). Other OCONUS locations may have local tidal datum references—see Table 2-3. CONUS projects can be referenced to the NAD83/GRS80 ellipsoid and NAVD88. All OCONUS locales can be globally referenced to the WGS84 ellipsoid and local NWLON tidal gage, as applicable. Geodetic reference datums for most CONUS and OCONUS project areas are outlined in Tables 2-2 and 2-3.

Table 2-2. Geodetic and Hydraulic Datum References for USACE Flood Risk Management, Navigation, and HSPP Projects (CONUS).

Project Location	Geodetic Reference Horizontal	Geodetic Reference Vertical	Hydraulic/Tidal Reference
Inland rivers, pools, reservoirs, etc.	NSRS (NAD83)	NSRS (NAVD88)	USACE modeled LWRP LWRP or pool
Coastal (tidal waters) Navigation projects HSPP projects	NSRS (NAD83)	NSRS (NAVD88)	NOAA NWLON (NTDE) hydrodynamically modeled Local Mean Sea Level (LMSL) or MLLW (navigation projects) between NWLON stations
Great Lakes	NSRS (NAD83)	NSRS (IGLD85) [1]	NOAA NWLON hydrodynamically modeled local IGLD85

[1] A separate IGLD85 datum is specified for Lakes Ontario, Erie, Huron, Michigan, and Superior.

Great Lake	IGLD85 Chart Datum	Ordinary High Water Mark (Section 10)
Superior	601.1 ft	603.1 ft
Michigan-Huron	577.5	581.5
St. Clair	572.3	576.3
Erie	569.2	573.4
Ontario	243.3	247.3

Hydraulic slopes are specified for connecting channels (e.g., Detroit River, St. Clair River, and St. Marys River, Niagara River, St Lawrence River). Additional details on IGLD are in Chapter 6.

Table 2-3. Geodetic and Hydraulic Datum References for USACE Flood Risk Management, Navigation, and HSPP Projects (OCONUS).

Project Location	Geodetic Reference Horizontal	Geodetic Reference Vertical	Hydraulic/Tidal Reference
Alaska	NSRS (NAD83)	NSRS (NAD83/GRS80) local datums or NAVD88	NWLON tide gages (LMSL/MLLW)
Puerto Rico	NSRS (NAD83)	PRVD02 [1]	Gage PBM 975 5371A (San Juan)
U.S. Virgin Islands:			
St. Thomas	NSRS (NAD83)	VIVD09 [1]	Gage 975 1639 F (Charlotte Amalie)
St. Croix	NSRS (NAD83)	VIVD09	Gage 975 1401 M (Lime Tree Bay)
St. Johns	NSRS (NAD83)	VIVD09	Gage 975 1381 Tidal 2 (Lameshur Bay)
Hawai'i			
Kaua'i	NSRS [2] (NAD83)	Local Tidal MLLW	Gage 161 1400 (Nawiliwili) Tidal 5
O'ahu	NSRS (NAD83)	Local Tidal MLLW	Gage 161 2340 BM 8
Moloka'i	NSRS (NAD83)	Local Tidal MLLW	Gage 161 3198 Tidal 10
Lana'i	NSRS (NAD83)	Local Tidal MLLW	(Univ of Hawaii gage-Kaumalapau)

Table 2-3 (Continued). Geodetic and Hydraulic Datum References for USACE Risk Management, Navigation, and HSPP Projects (OCONUS).

Project Location	Geodetic Reference Horizontal	Geodetic Reference Vertical	Hydraulic/Tidal Reference
Hawai'i (Contd):			
Maui	NSRS (NAD83)	Local Tidal MLLW	Gage 161 5680 BM A
Hawai'i	NSRS (NAD83)	Local Tidal MLLW	Gage 161 7760 Tidal 4
Kaho'olawe	NSRS (NAD83)	Local Tidal "MLL"	n/a ["Mean Lower Low" datum]
Ni'hau	NSRS (NAD83)	Local Tidal MLLW	n/a [3]
American Samoa:			
Tutuila (Pago Pago)	NSRS (83) HARN 2002	American Samoa Vertical Datum of 02	Gage PBM 177 0000 PBM S
Tau	NSRS (83) HARN 2002	American Samoa Vertical Datum of 02	n/a
Aunuu	NSRS (83) HARN 2002	American Samoa Vertical Datum of 02	n/a
Ofu	NSRS/ HARN 02	USGS 1963	n/a
Rose	NSRS/ HARN 02	USGS 1963	n/a
Olosega	NSRS/ HARN 02	USGS 1963	n/a

Table 2-3 (Continued). Geodetic and Hydraulic Datum References for USACE Risk Management, Navigation, and HSPP Projects (OCONUS).

Project Location	Geodetic Reference Horizontal	Vertical	Hydraulic/Tidal Reference
American Somoa (Cont)			
Swains	NSRS/ HARN 02	USGS 1963	n/a
Guam	NSRS (83) HARN 1993	Guam Vertical Datum of 2004 GUVD04	Gage 163 0000 PBM TIDAL 4
Northern Marianas Islands:			
Saipan	NSRS (83) 2002 HARN	No. Marianas Vert Datum of 2003 (NMVD03)	Gage 163 3227 PBM UH-2C
Rota	NSRS (83) 2002 HARN	No. Marianas Vert Datum of 2003 (NMVD03)	n/a [Tidal 3]
Tinian	NSRS (83) 2002 HARN	No. Marianas Vert Datum of 2003 (NMVD03)	n/a [Tidal 1]
Aguijan	NSR (83) 2002 HARN	No. Marianas Vert Datum of 2003 (NMVD03)	n/a

Table 2-3 (Concluded). Geodetic and Hydraulic Datum References for USACE Risk Management, Navigation, and HSPP Projects (OCONUS).

Project Location	Geodetic Reference Horizontal	Geodetic Reference Vertical	Hydraulic/Tidal Reference
Marshall Islands:			
Kwajalien	WGS84	Local Tidal	Gage 182 0000 Tidal 8
Palau/Babeldaup	WGS84	Local Tidal	n/a
Micronesia (Federated States):			
Chuuk	WGS84	Local Tidal	184 0000 (Chuuk)
Kosrae	WGS84	Local Tidal	n/a
Pohnpei	WGS84	Local Tidal	n/a
Yap	WGS84	Local Tidal	n/a
Wake Island	NSRS (83)	Local Tidal	Gage 189 0000
Midway (Sand Island)	NSRS (83)	Local Tidal	Gage 169 9910 Tidal 21
Johnson Atoll	NSRS (83)	Local Tidal	Gage 161 9000 PBM MON JON

NOTE: Data in this table were obtained from Jacksonville District, Honolulu District, NGS, and CO-OPS. It is considered current as of 2009. NGS and CO-OPS are periodically updating horizontal and vertical references in these OCONUS areas; thus, users should contact the local District, NGS, and/or CO-OPS to ensure the latest reference datums are being used.

[1] PRVD02 and VIVD09 are currently (2010) being updated based on new leveling and gravity data
[2] All horizontal datums in Hawaiian Islands based on HARN 1993 adjustment
[3] n/a – indicates reference datum or gage is "not available" or is uncertain

b. Inland waterway reference datums. Various datums are used in controlled and free flow portions of inland river systems. Gages on the main stream Mississippi, Ohio, and Missouri Rivers, and their tributaries, are referenced to various datums. Gage zeros may be referenced to a geodetic datum, a low water reference plane, an arbitrary stage elevation, or a purely arbitrary elevation. Gage records maintained and published by USACE, USGS, or other agencies will should clearly define the gage zero reference datum. Some gages have been updated to

NAVD88; however, in many cases this was accomplished using VERTCON/CORPSCON approximations.

(1) Low water reference planes. On the Mississippi River, between the mouths of the Missouri and the Ohio Rivers (the Middle Mississippi River), depths and improvements are referenced to a LWRP. No specific LWRP year is used for the Middle Mississippi north of Cairo, IL. Below Cairo, IL, depths and improvements along the Mississippi River are referenced to a dated LWRP (e.g., LWRP74, LWRP93, LWRP07). These hydraulic-based reference planes are established from long-term observations of the river's stage, discharge rates, and flow duration periods—often developed about the 97-percent flow duration line. The elevation of the LWRP drops gradually throughout the course of the Mississippi; however, some anomalies in the profile are present in places. The gradient is approximately 0.5 ft per river mile in some reaches. The ever-changing river bottom will influence the LWRP. Changes in the stage-discharge relationship will influence the theoretical flow line for the LWRP. The LWRP is periodically updated by District H&H branches in the Mississippi Valley Division (MVD)—see Figure 2-3.

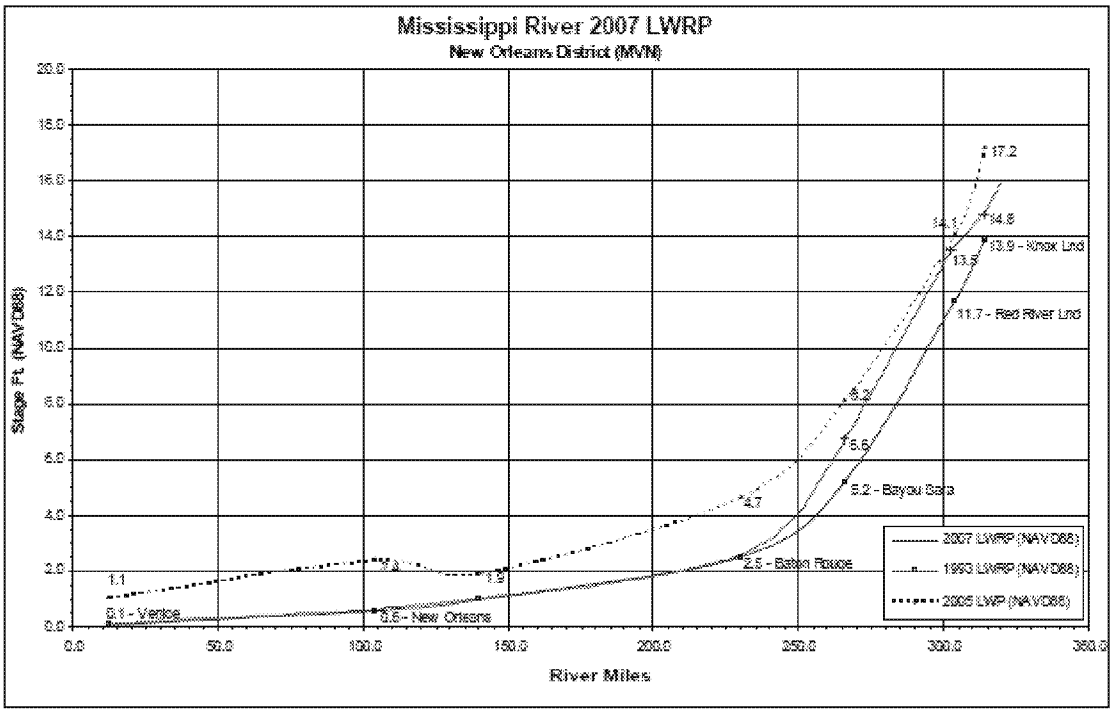


Figure 2-3. Lower Mississippi River LWRP [1993/2005/2007] relationships—New Orleans District. (CEMVN)

(2) Controlled pools. Between river control structures, low water pools are used to reference maintained navigation depths. Since these pools themselves may exhibit some slope, sufficient gages/benchmarks within the pools may need to be established to account for any slope. In the Upper Mississippi River pools, flow profiles between the upper and lower dams establish "project pool" elevations and "ordinary high water profiles." Elevations/stages of

"primary control points" or "hinge/pivot points" between locks and dams are also defined for each pool.

(3) Reservoirs. Most upland reservoir elevations are referenced to an orthometric datum—i.e., a legacy NGVD29 or NAVD88.

c. Sample inland river gage datums and stages. The following examples in Table 2-4 are taken from selected gages covering some 1,700 miles of the Mississippi River from Minneapolis, MN to the Gulf. These sample gages (from over 200) illustrate the varied datums and gage zero/stage references used on inland river systems.

Table 2-4. Reference Elevations on Selected Gages—Upper, Middle, and Lower Mississippi River.

Gage	River Mile	Gage Datum Elevation (ft)	Flat Pool Elevation (ft)	Stage at Flat Pool (ft)
[St. Paul District: most gage datum elevations are set to 700.0 ft or 600.0 ft ... referenced to NGVD29]				
St. Anthony L/D (U)	654.1	700.0	796.5	96.5
L&D 5 (L)	738.1	600.0	651.0	51.0
Winona, MN	725.7	640.0	643.8	5.8
L/D 7 (L)	702.5	600.0	631.0	31.0
L/D 10 (L)	615.1	600.0	603.0	3.0
[Rock Island District: gage datum elevations are referenced to MSL 1912]				
L/D 11 (L)	583.0	588.2	592.0	3.8
Ft Madison Br., IA	383.9	6.8	518.2	518.2
L/D 22 (U)	301.2	446.1	459.5	13.4
[St. Louis District: gage datum elevations are referenced to NGVD29]				
L/D 22 (L)	301.2	446.1	449.1	3.0
L/D 24 (U)	273.5	421.81	445.5	445.5
L/D 27 (L)	185.1	350.0	380.5	380.5

Table 2-4 (Concluded). Reference Elevations on Selected Gages—Upper, Middle, and Lower Mississippi River.

Gage	River Mile	Gage Datum Elevation (ft)	Flat Pool Elevation (ft)	Stage at Flat Pool (ft)
			Low Water Reference Plane [open flow]	
St. Louis, MO	179.6	379.94	376.4	
Cape Girardeau, MO	52.1	304.65	309.9	
Cairo, IL (Ohio Riv.)	2.0	270.47	277.9	
	Above Head of Passes			
New Madrid, MO	889.0	255.48	303.48	
Vicksburg, MS	435.7	46.23	99.47	
Red River Landing	302.4	0.0	60.94	
New Orleans	102.8	0.0	21.27	
Head of Passes	-0.6	0.0	12.03	

d. Datums on other river systems. Gages in portions of the Ohio River are referenced to the "Ohio River Datum (ORD)." Flood stages are relative to the gage zero—e.g., at Cincinnati, the 52.0 ft flood stage is relative to the 429.613 ft gage zero (ORD). The Green River is referenced to the "1929 General Adjustment" which may be equivalent to NGVD29. Gages on the Missouri River and tributaries are referenced to "MSL." Other USACE projects have similar local river datum references that are hydraulically modeled—e.g., Atchafalaya River, Columbia River, Snake River, etc.

e. Variety of inland reference datums. The following excerpt from the University of Illinois "Natural Resources Geospatial Data Clearinghouse" illustrates the need to have reliable conversions between legacy datums and to standardize datums for civil works applications.

> *"Each benchmark is tied to a specific known elevation marker, called a datum. Agencies working in Illinois rely on several vertical datums which are not easily related to each other. Some of these include:*
>
> *NAVD88, the North American Vertical Datum of 1988.*
> *NGVD29, the National Geodetic Vertical Datum of 1929.*
> *The City of Chicago Datum, one of numerous legacy municipal datums.*
> *NGVD12 [i.e., 1912 Adjustment], used by the USACE Rock Island District for management of the Mississippi River.*
> *The Ohio River Datum, used by the USACE Louisville District for management of the Ohio River.*

Approximate conversions between these legacy data exist, but their use degrades the precision of the measurements. During emergencies, these inconsistencies can cause confusion and waste valuable time. Multiple datums also make it virtually impossible to create useful, accurate, seamless maps and supporting flood data for the state. An example of the problems that multiple vertical datums can cause can be found in the Mississippi Valley in Northern Illinois, where levee top surveys are in NAVD88 and water level measurements are in NGVD12.

Because of the large number of different datums, numerical conversions between networks are approximate. This fact lowers the accuracy of existing elevation data sets."

CHAPTER 3

Survey Accuracy Standards and Procedures for Connecting Projects to the National Spatial Reference System

3-1. General. As outlined in Chapter 1, the designed, constructed, and maintained elevation of a project must be referenced to a consistent framework, or vertical datum. References to two primary and distinct reference datums are required:

a. Hydraulic or Water Level Datums. Water surface elevation relative to a locally defined hydraulic reference plane on a river, pool, lake, or tidal body, from which flood protection design elevations or navigation grades are derived.

b. Geodetic or Orthometric Datums. Three-dimensional horizontal and vertical frameworks defined relative to a federally recognized terrestrial and/or extraterrestrial (satellite-based) reference datum.

Throughout the life cycle of a project, these two reference datums must be accurately established, maintained, and defined relative to "Permanent Bench Marks" (PBMs) established at each project site, hereinafter termed “Primary Project Control Points" (PPCP). Supplemental, or "Local Project Control Points" (LPCP), and "Temporary Bench Marks" (TBM) used for construction orientation and grade, are established from these PPCPs. These PPCPs must be firmly connected to nationwide vertical reference frameworks—the NSRS, in coastal regions the NWLON, and defined datums in OCONUS areas. The following paragraphs in this chapter provide guidance on establishing PPCPs and LPCPs at each project site.

3-2. Definitions. The following definitions apply to terms used in this and subsequent chapters.

a. Geodetic Surveying. Survey measurements performed to relate project features to a nationwide reference datum (i.e., the NSRS), typically using static GPS observations over long baselines or precise geodetic differential leveling methods. Geodetic surveys discussed in this guidance are performed for nationwide geospatial reference purposes only; they are not applicable to local project design and construction surveys outlined in the next paragraph.

b. Topographic or Engineering and Construction Surveying. Surveys used to set project control monuments on levees and related flood protection structures, topographic surveys for planning and design, construction stake out, levee cross-sections, levee profiling, etc. Engineering and construction surveys are performed using total stations, differential levels, and/or GPS/RTN methods; following the techniques outlined in EM 1110-1-1005 (*Control and Topographic Surveying*). Procedures and accuracies generally follow "Third-Order" methods described in that manual. These surveys, or fixed control monuments/bench marks established therefore, are usually not included in the NSRS; however, there may be exceptions.

c. Primary Project Control Points (PPCP). Bench marks set on or near a project that are connected with and published in the NSRS, and are used to densify local project control monuments or develop project features. These NSRS bench marks may be established by the NGS, USACE, or other agencies. Each USACE project and water level gage should have at least one PPCP.

d. Local Project Control Points (LPCP). Monuments (PBMs, TBMs, hubs, etc.) used to reference project features, alignment, elevations, or construction. Monuments may be atop levees (e.g., PBMs set at levee sector "points of intersection" or PIs) or offset to the levee alignment. These monuments will usually have local X-Y-Z (SPCS) coordinates along with local project station-offset coordinates. LPCPs are usually not part of the published NSRS; however, they should be directly established from or relative to a PPCP described above. A minimum of three project control bench marks (PPCPs and/or LPCPs) are required for advertised construction plans and references to water level gages.

e. Project NSRS Network Accuracy. This refers to the spatial accuracy of a project's PPCP relative to NSRS points (bench marks) in the nearby geographical region. NSRS regional network accuracy is significant in defining relative orthometric and hydraulic gradient relationships between river gages or tidal gages. It is also significant in defining accuracy relationships between elevations of points established by various federal, state, or local agencies. The NSRS network accuracy is NOT significant or applicable to local project construction stakeout—see "Local Network Accuracy" below. Depending on the type of project and surrounding terrain gradients, required NSRS network elevation accuracies may range from ± 0.1 ft to ± 1 ft. The USACE has adopted a nominal NSRS accuracy standard of ± 0.25 ft.

f. Local Network Accuracy. (Engineering and construction accuracy). Spatial accuracy of a LPCP or project features relative to nearby local reference monuments on the project. Local project accuracy is critical for construction with X-Y-Z tolerances at the ± 0.05 ft level. Local accuracy tolerances are always much smaller than NSRS network accuracy tolerances.

g. Survey Accuracy Standards. Specified target positional accuracy tolerances for a project control monument/bench mark or other project feature (e.g., levee profile, intake structure, inverts, top of floodwall, ground shots).

h. Survey Specifications. Survey procedures and equipment requirements.

i. Uncertainty. The propagated network, instrumentation, and observation errors on a surveyed PBM or feature elevation. Roughly synonymous with "project" and "local" accuracies described above. Refer to Chapter 9 for a more detailed discussion of propagated elevation uncertainties on levee grades or navigation projects.

j. Global Positioning System (GPS) Surveys. "GPS surveys" referenced in this manual imply differential carrier phase GPS baseline measurements—also termed "DGPS" surveys. Code phase GPS or autonomous GPS positioning accuracies are not suitable for project control. A number of DGPS survey methods may be employed in establishing project control, variously termed "Static DGPS Baselines," "Real Time Network" (RTN), "Real Time Kinematic" (RTK), "Post-Processed Kinematic" (PPK), and "Virtual Reference Network" (VRN). Refer to EM 1110-1-1003 (*NAVSTAR GPS Surveying*) for details on performing these carrier phase DGPS surveys.

k. Continuously Operating Reference Stations (CORS). The NGS coordinates a GPS network of over 1,400 Continuously Operating Reference Stations (CORS) throughout North America and over 1,800 worldwide, as of 2010. Each CORS site provides GPS carrier phase and code range measurements in support of three-dimensional positioning activities throughout the United States and its territories. The CORS system enables relative positioning accuracies to better than 0.25 ft relative to the NSRS, both horizontally and vertically.

l. Online Positioning User Service (OPUS). OPUS is an interactive/Internet-based NGS software system that processes static GPS baselines relative to the CORS. It provides near real-time X-Y-Z coordinates relative to the NSRS. OPUS processes GPS data files with the same models and tools which help manage the CORS network, resulting in "CORS/OPUS" coordinates which are both highly accurate and highly consistent with other users. A computed "CORS/OPUS" NSRS position on a bench mark can also be shared publicly via the NGS/NSRS database. Planned upgrades to OPUS may allow merging CORS baselines with conventional GPS network, topographic, and/or differential leveling observations.

3-3. Distinction between NSRS Control and Local Project Control.

a. Project control. A critical distinction must be made between:

(1) Geodetic Control. The regional "geodetic survey" process of referencing USACE project elevations to NAVD88 or NAD83 relative to nearby points on the NSRS (PPCP), and

(2) Local Engineering & Construction Control. Engineering and construction surveying requirements necessary to design, align, stake out, and construct a local flood or water control structure, a HSPP, or a navigation project relative to local project control (LPCP).

b. Control accuracy. Figure 3-1 illustrates the distinction between NSRS network and local project control accuracies. The PPCP has been connected to other adjacent points in the NSRS to an accuracy of ± 0.22 ft. This "NSRS Network Accuracy" is based on the adjustment statistics from the point's connection, such as GPS baseline reductions, differential leveling loop closures, etc. The adjusted NSRS elevation of 298.72 ft is assumed absolute and is used to establish elevations on the two levee LPCP monuments shown in Figure 3-1. The elevations of these levee LPCPs may be determined by various topographic survey methods—levels, DGPS, RTN, RTK, or total station. Figure 3-1 depicts dashed lines from the PPCP to each local control PBM at Station 0+00 and Station 15+72.4; indicating GPS surveys were used to obtain elevation differences over each baseline. Given observed differential elevations over each baseline from the PPCP to Stations 0+00 and 15+72.4, NAVD88 elevations are transferred to these local monuments. Due to error propagation, these local LPCP elevations have a slightly larger NSRS "network" accuracy than the PPCP. However, their "Local Network Accuracy" of ± 0.1 ft is based on the observed GPS baseline closure accuracies. Had differential levels been run along the levee between stations 0+00 and 15+72.4, then the level misclosure would give an indication of the relative accuracy. The LPCPs thus have both a local (relative) accuracy needed for construction and a NSRS network accuracy needed for regional engineering and mapping purposes. These resultant local and network accuracies may also be termed "uncertainties."

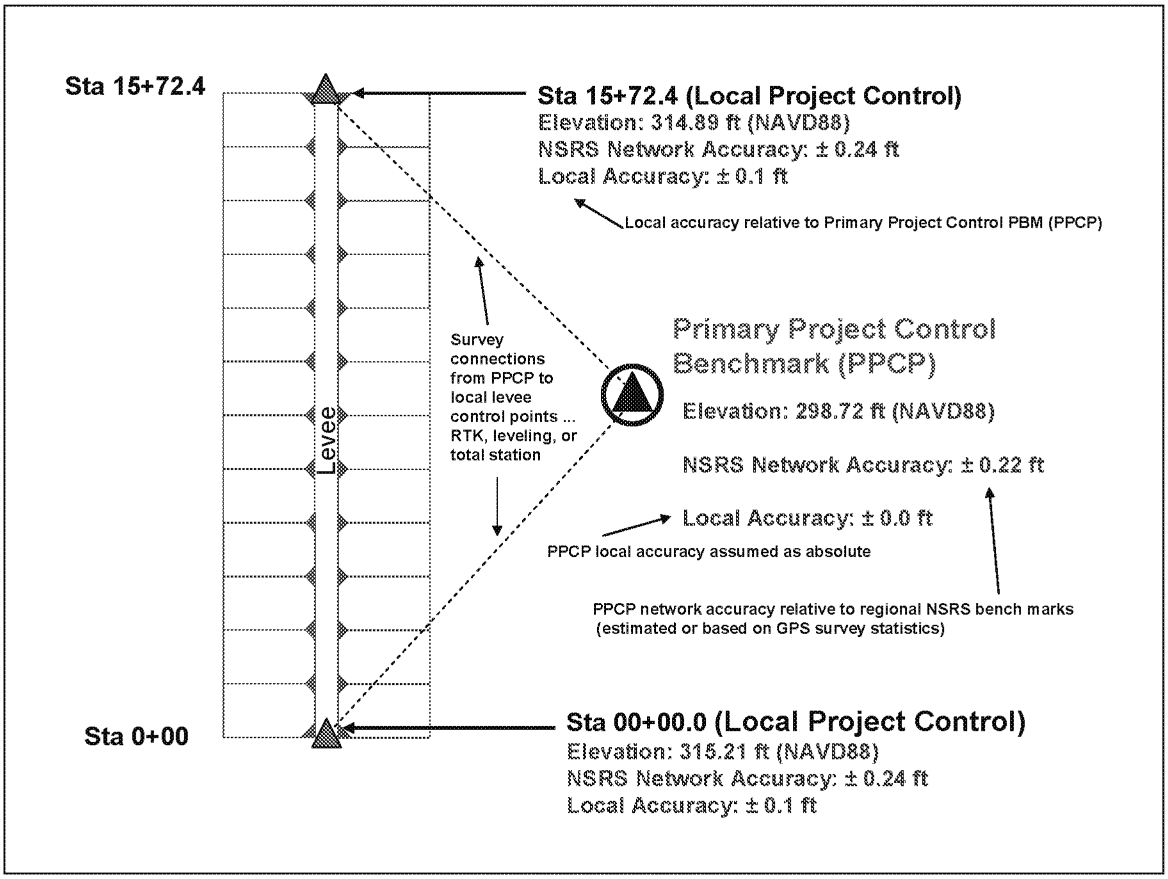


Figure 3-1. Distinction between Primary Project Control and Local Project Control points on a simple levee segment-- Network and Local Accuracies.
(Hydraulic stage or tidal datum relationships not shown)

c. Control survey method. The survey method used to connect local project control PBMs and TBMs is dependent on the accuracy requirements of the project. DGPS, RTK, or RTN methods (generally accurate to ± 0.1 ft) will normally suffice for design and construction of most USACE civil works projects. More accurate differential leveling may be required for water control structures, locks, dams, floodwalls, etc. If the above distinction between local and network project accuracies is not clearly understood, then unnecessary USACE resources may be expended performing higher accuracy "geodetic" surveys to achieve elevation accuracies that have no hydrologic or hydraulic engineering requirement; either within USACE or in conjunction with other agencies.

d. Control database. The "USACE Survey Monumentation Archival and Retrieval Tool" (U-SMART) database options allow linking PPCPs with LPCPs on a specific USACE flood risk management or navigation project. Details on U-SMART are discussed in Section 3-13.

3-4. Recommended Accuracy Standards for USACE Project Control. PPCP connections to the NSRS are made by field survey techniques—typically by traditional differential leveling or by differential GPS height observations between published NSRS PBMs and PPCPs.

a. PPCPs must be geospatially referenced such that designed protection elevations are:

(1) Consistent with federally mandated vertical datums (e.g., NAVD88, IGLD85).

(2) Consistent with federally mandated horizontal datums (e.g., NAD83).

b. The minimal accuracy standards in Table 3-1 apply to USACE PPCPs that are established relative to the regional NSRS network; that is these PPCPs are directly connected by differential leveling and/or GPS baselines to nearby NSRS points. These NSRS connection observations to PPCPs shall be submitted to NGS for inclusion in the NSRS. These are minimal accuracy standards that are believed adequate for most inland flood risk management and coastal projects. The accuracy standards in Table 3-1 do NOT apply to supplemental LPCPs, topographic, or construction surveys conducted from these primary points—see paragraph 3-3 on the critical distinctions between "primary" and "local" project control.

Table 3-1. Recommended Minimal or Target Accuracy Standards for Connecting Primary Project Control Points on USACE Projects to the US Department of Commerce NSRS Network.

	NSRS Accuracy (95%) [1]	Reference Datum (CONUS)
Vertical	± 0.25 ft (± 8 cm)	NAVD88
Horizontal	± 2 ft (± 60 cm) [2]	NAD83

[1] Accuracies are at the 95% confidence level relative to regional points published by NOAA on the NSRS.
[2] Horizontal accuracy is for global reference purposes—achievable DGPS derived accuracies are currently ± 0.2 ft typical.

c. These NSRS network accuracy standards at the ± 0.25 ft level are believed to be representative of the nominal accuracy requirements for the vast majority of USACE levee systems and related water control projects. These accuracies should support flood forecasting models, stage-discharge relationships, flood inundation modeling, channel design, levee freeboard design, risk assessment, and related river hydraulics work. Additional details on evaluating project accuracy requirements are covered in later sections of this chapter.

d. There may be levee or river segments where these standards are either too rigid or perhaps require tightening, as might be the case in high subsidence regions. This decision on the required project accuracy should be left to those performing hydrology and hydraulics studies over a watershed or flood risk management region. If such technical guidance is not available, then the criteria in Table 3-1 may be used by default. If more rigid accuracy standards are required, then refer to the guidance in Chapter 8.

e. It is also essential that the required survey accuracy be derived from realistic engineering applications associated with a flood risk management system or project. This is best summarized in Appendix A of FEMA's "*Guidelines and Specifications for Flood Hazard Mapping Partners*" (FEMA 2003) which emphasizes the need for establishing reasonable map accuracy and resolution specifications for flood insurance studies:

> *"The specified accuracy of FIRM work maps produced by Mapping Partners must be sufficient to ensure that the final FIRMs produced by FEMA can be reliably used for the purpose intended. However, the accuracy and resolution requirements of a mapping product must not surpass that required for its intended functional use. Specifying map accuracies in excess of those required results in increased costs, delays in project completion, and reduction in the total numbers of new or revised products that the Mapping Partner may generate. Mapping accuracy requirements must originate from functional and realistic accuracy requirements."*

The above statement makes it imperative that the project's functional and realistic accuracy requirements be defined based on the requirements of a flood system profile model or navigation project model. Once the functional accuracy requirement is defined, USACE surveyors can then define the appropriate survey specifications needed to meet that accuracy.

f. The required NSRS network accuracy of a primary or local project control point (and indirectly to any topographic feature on the project, such as a levee crest, floodwall cap, pump station invert, etc.) is also determined by the engineering requirement for regional consistency between these points. These regional network accuracy requirements relative to the NSRS may be contingent on compliance with one or all of the following:

(1) USACE, USGS, FEMA, NOAA or other agency hydrologic or hydraulic analyses, models, or water surface profiles between and within large river reaches/basins and river stage gages.

(2) USACE/FEMA/other flood inundation mapping study accuracies.

(3) Consistency with FEMA flood insurance study accuracies performed under FEMA's National Flood Insurance Program (NFIP)—Flood Hazard Maps, (Digital) Flood Insurance Rate maps (FIRM/DFIRM), etc.

(4) Consistency with Federal mapping accuracy standards in the project area—e.g., USGS.

g. NSRS network horizontal accuracy standards (± 2 ft) in Table 3-1 are obviously not critical for hydraulic engineering purposes. This nominal horizontal standard can be easily exceeded with minimal observation times using various DGPS methods. This would be done in cases where recovered bench marks do not have a horizontal position. When static DGPS observations are conducted at a point for elevation determination, horizontal accuracies relative to the NSRS will usually be around the ± 0.2 ft level.

3-5. FEMA Accuracy Standards for Flood Insurance Rate Maps. Since regional conformance with FEMA NFIP studies is an essential goal of any USACE flood risk management project and/or study, both USACE and FEMA must be on the same vertical datum—i.e., NSRS NAVD88—or, at minimum, have a firmly established relationship between different vertical datums. FEMA standards and specifications clearly detail this intent. Tables 3-2 and 3-3, taken from Appendix A (*Guidance for Aerial Mapping and Surveying*) of FEMA's "*Guidelines and Specifications for Flood Hazard Mapping Partners*" (FEMA 2003), illustrate the required FIRM/DFIRM accuracy requirements relative to the NSRS. In summary, FEMA NSRS regional elevation accuracy standards are (1) standard 2-foot equivalent contour interval accuracy ($Accuracy_z$ = 1.2 foot) appropriate for flat terrain, and (2) standard 4-foot equivalent contour interval accuracy ($Accuracy_z$ = 2.4 foot) appropriate for rolling to hilly terrain. In effect, USACE flood protection structure elevations should have relative NSRS regional network accuracies at or better than the above tolerances in order to be consistent with FEMA flood insurance studies, FIRMs, DFIRMs, etc. The USACE control survey standards and specifications in this guidance document will yield NSRS network accuracies well within these FEMA NSRS accuracy standards. These more precise USACE accuracy standards result from more rigorous hydraulic engineering and levee design requirements than those needed for NFIP studies.

Table 3-2. FEMA Vertical Accuracy Standards. (FEMA 2003)

NMAS Contour Interval	NMAS VMAS 90%	NSSDA $Accuracy_z$ 95%	NSSDA $RMSE_z$	ASPRS 1990 Class 1/2/3 Limiting $RMSE_z$
2 Foot	1 ft	1.2 ft	0.6 ft (18.5 cm)	0.7 ft (Class 1) 1.3 ft (Class 2) 2.0 ft (Class 3)
4 Foot	2 ft	2.4 ft	1.2 ft (37.0 cm)	1.3 ft (Class 1) 2.7 ft (Class 2) 4.0 ft (Class 3)

Table 3-3. FEMA Horizontal Accuracy Standards. (FEMA 2003)

NMAS Map Scale	NMAS CMAS 90%	NSSDA $Accuracy_r$ 95%	NSSDA $RMSE_r$	ASPRS 1990 Class 1/2/3 Limiting $RMSE_r$
1 " = 500 ft	16.7 ft	19.0 ft	11.0 ft	7.1 ft (Class 1) 14.1 ft (Class 2) 21.2 ft (Class 3)
1 " = 1,000 ft	33.3 ft	38.0 ft	22.0 ft	14.1 ft (Class 1) 28.3 ft (Class 2) 42.4 ft (Class 3)
1 " = 2,000 ft	40.0 ft	45.6 ft	26.3 ft	28.3 ft (Class 1) 56.5 ft (Class 2) 84.9 ft (Class 3)

3-6. <u>USGS National Map Accuracy Standards</u>. USGS topographic maps at 1:24,000 (1" = 2,000 ft) are generally designed to be accurate to one-half the contour interval on the map. Thus, for a standard 2 ft contour map, the estimated vertical accuracy is ± 1 ft (at a 90% confidence). The horizontal accuracy is specified at $1/30^{th}$ of the scale, or ± 67 ft for a 1 in. = 2,000 ft (7.5 minute) quadrangle. The targeted NSRS network accuracy standards performed under this guidance will significantly exceed these USGS mapping accuracy standards.

3-7. <u>Local Topographic, Engineering, and Construction Survey Accuracy Standards</u>. Local levee alignment LPCP bench marks (e.g., PIs, PTs, PCs, gage references, etc.) and topographic features (levee profiles, cross-sections, etc.) should be positioned relative to the nearest PPCP that has been referenced to the NSRS. This PPCP(s) may be a published NGS bench mark or a USACE monument that has been connected to (and input into) the NSRS. These local project control surveys will typically be performed over short distances—for example, within range of an RTK base station, within the coverage of a GPS Real Time Network (RTN), or within a reasonable distance for differential leveling or total station observations. Field survey procedures will follow engineering and construction survey guidelines in EM 1110-1-1005 (*Control and Topographic Surveying*). Recommended survey accuracies of feature points are listed in Table 3-4.

Table 3-4. Recommended Local Project Elevation Accuracies for Flood Risk Management Project Features.

	Relative Accuracy (95%)	Reference Datum
Levee or floodwall control bench marks:	± 0.15 ft	NAVD88/NAD83
Hard topographic features:	± 0.3 ft	NAVD88/NAD83
Ground shots:	± 0.5 ft	NAVD88/NAD83
Construction stake out	± 0.01 to 0.05 ft	Local site
General floodplain mapping (GIS)	± 0.5 to 2 ft	NAVD88/NAD83

NOTES:

Local project control will typically have two horizontal references: (1) a local SPCS system, and (2) the construction station/chainage-offset system.

The above accuracies are not relative to the regional NSRS but are for local topographic and construction purposes. Elevations are reported relative to NSRS vertical datum.

The latest geoid model published by NGS will be used to estimate and correct local geoid undulations for all topographic densification using RTK/RTN methods. At longer distances greater than 3 miles from the RTK base, frequent calibration check points are recommended if a standard RTK/RTN site calibration/localization process is not feasible—see EM 1110-1-1005.

a. Local horizontal accuracies should generally be within the tolerances for vertical accuracies shown in Table 3-4. When using RTK/RTN methods, the horizontal accuracies will be slighter better—and over current RTK/RTN application distances, a ± 0.1 ft (± 3 cm) local relative accuracy should be achieved at any type of point located (assuming appropriate site calibration procedures are followed). For example, the horizontal distance between two levee PIs 2,000 ft apart will be accurate horizontally to the ± 0.1 to 0.2 ft level when these points are connected using either RTK/RTN or total station EDM observations, and usually better than ± 0.05 ft vertically when differential levels are run. These local (relative) accuracy levels are sufficient for any levee stationing stake out needed for construction or maintenance grading. Thus a PI monument will have a local project stationing-offset and elevation coordinate for maintenance and construction, and will also be referenced to the NSRS (NAD83 and NAVD88) for regional mapping orientation purposes.

b. As illustrated on Figure 3-1, NSRS network accuracies of any local bench mark (LPCP) or feature point will be slightly larger than the accuracy of the controlling (primary) NSRS bench mark—due to error propagation in the survey process. For example, if an RTK base is set over a NGS NSRS network point with an established (estimated or published) NSRS "network" accuracy of ± 0.22 ft, and a local project bench mark atop the levee on a PI is shot in with an estimated RTK "precision" of ± 0.1 ft, then the estimated (propagated) accuracy of the PI bench mark is roughly ± 0.24 ft— as computed from $[0.22^2 + 0.1^2]^{½}$. If this PI point is later occupied with an RTK base to cut in hard levee features or levee crest ground profiles, then the estimated (propagated) accuracy of these elevations would be roughly ± 0.26 ft relative to the regional NSRS—i.e., $[0.24^2 + 0.1^2]^{½} = \pm 0.26$ ft.

3-8. <u>Hierarchy of Preferred Survey Methods for Establishing New Primary Bench Marks Relative to the NSRS</u>. Published NSRS bench marks of Second-Order or higher order should be used as PPCPs when they are on or near a project. When no existing (or published) NSRS vertical control is available near the project, PPCPs must be set to an established density, accuracy, and observing specification. Newly established project control must also be published in the NSRS by forwarding geodetic observations and descriptive data to the NGS. The essential purpose for establishing this primary control is to provide assurance that navigation grades and flood protection structure elevations measured from these PPCPs will be adequately referenced to the NSRS (currently NAVD88). A variety of survey procedures may be used to establish new PPCPs. Table 3-5 details a hierarchy of survey methods by which project elevations and grades can be connected to the NSRS (and the NWLON if applicable). The order of preference in Table 3-5 is somewhat dependent on the mechanism for inputting data to the NSRS—item [II] being the simplest, and [III] and [IV] currently being the most difficult.

a. Preferred survey method. The survey method chosen from the Table 3-5 will have a major impact on the amount of field effort and cost. Preference [I] obviously requires minimal field work other than verifying the current adequacy and stability of the existing NSRS bench mark. The "CORS/OPUS method"—Preference [II]—at a new PPCP can be performed for economically using a one-man survey crew and OPUS-based software to input the data to the NSRS. Positioning this same point by NSRS networked baseline connections—Preference [III]—would require a 3- to 4-man survey crew. If Blue Book techniques are used to input this data into the NSRS, the total cost to establish this point could be 5 to 10 times the cost of Preference [II]. This cost will be significantly reduced when NGS develops software to replace the Blue Book. Differential leveling ties —Preference [IV]—will be cost-effective only over short lines where Third Order closure tolerances can be maintained. They will also require connections with at least two or more published NSRS bench marks. Higher-order instrumentation and procedures will be required over longer lines, significantly increasing field effort. Inputting level line data into the NSRS via Blue Book methods also requires significant administrative effort—the cost of which may exceed the cost of the field work for short lines. NGS is developing software that allows simplified input of leveling data to the NSRS. From the above, it is obvious that effort should be made to locate and utilize existing NGS NSRS vertical control as PPCPs—and establish as few as possible new points. When new primary points must be set, CORS/OPUS methods [II] should be used to the maximum extent possible.

Table 3-5. Preferred Hierarchy of Survey Methods for Establishing New PPCPs Relative to the NSRS.

Order of Preference	Survey Method	NSRS Input Method	Notes
[I]	Use existing NSRS control	not applicable	NSRS check surveys only
[II]	GPS: CORS/OPUS	OPUS input [1]	Restricted to CORS within 200 miles
[III]	GPS: Networked baselines to nearby NSRS marks if CORS/OPUS solutions cannot be performed	Blue Book or OPUS input [1]	Include any CORS baselines in adjustment
[IV]	Differential Leveling from NSRS points	Blue Book or OPUS input [1]	Setting primary points at levees or gages

[1] Various NSRS input methods via OPUS-based solutions are being developed by the NGS. Monitor NGS websites for the current versions of OPUS data input techniques to the NSRS.

b. PPCP coverage density. The density, or spacing, of PPCPs that are directly connected to the NSRS will vary with the geographic extent and type of project. Ideally, a PPCP PBM should be located as close as possible to the project—preferably on one of the project's reference PBMs. In general, each project should have at least one PPCP relatively close to the project and a published PPCP reference bench mark a short distance (< ¼ mile to minimize number of level setups) from a river or tide gage.

(1) Levee projects. Any suitable existing levee control monument may be used as a new PPCP. For extensive levee segments, PPCPs spaced every 15 to 20 miles will generally provide adequate coverage from which to perform any non-NSRS supplemental control observations to LPCPs needed to survey levee grades and features relative to NAVD88, such as by observing RTN/RTK or static DGPS baselines between the PPCP and the LPCPs. For projects that require

multiple PPCPs, the relative accuracy between PPCPs should adhere to the local survey accuracy requirements. Additional details on PPCP density requirements for large levee systems are covered in Chapter 6.

(2) Navigation and HSPP projects. Navigation projects should have a PPCP located as close as possible to the project since that PBM will likely be used for controlling surveys, grading, and dredging operations with RTN/RTK machine control techniques. Ideally a NOAA tidal PBM near the project site is designated as the PPCP and is used as both an RTK base and tidal calibration point. See Chapters 4 and 5 for details on establishing PPCPs on coastal projects.

c. Real Time Networks (RTN). Expanding use of RTN coverage throughout CONUS significantly minimizes the need for a dense network of PPCPs and LPCPs on project sites. Given most RTNs are directly referenced to the NSRS CORs stations, they are, in practice, a "PPCP," requiring only a sparse network of local PPCPs and/or LPCPs for site calibration of the RTN. RTNs, and successor GNSS technologies, are expected to eventually replace the need for monumented NSRS PPCPs; however local LPCP networks will likely still be required for construction site calibration and boundary referencing.

3-9. Preliminary Evaluation of Existing Project Control. For each project, a preliminary evaluation of the acceptability and reliability of existing project control and their reference datums must be made.

a. For example, the main issues to be evaluated for a project would include:

(1) That protection grade elevations are referenced to NAVD88 based on PPCPs published in the NSRS.

(2) That river gages owned and/or operated by the Corps (or other agency gages used by USACE) are referenced to NAVD88 based on control bench marks published in the NSRS, and that the relationship between the geodetic and hydraulic datums at the gage are firmly established and documented.

(3) That project drawings, CADD files, and related documents, contain full and complete metadata on PPCPs and LPCPs, and the relationship between the geodetic and hydraulic datums and any associated legacy datums.

b. Upon completing a preliminary evaluation for each project, it may be determined that no additional field survey work is required for connection to the NSRS. This would include:

(1) Projects that have been recently connected to the NSRS, such as those that were included in a NGS Height Modernization project.

(2) Projects with control firmly surveyed on NGVD29 and directly leveled to NSRS points that were subsequently readjusted to NAVD88.

(3) Projects that were recently connected to the NSRS by local sponsors, levee boards/districts, State DOT, or other local agency, but connections were not published in the NSRS.

c. If the initial assessment determines that the project datum is not referenced to the current NSRS, and a required accuracy tolerance is established, then the amount of field survey effort involved will be largely governed by the following factors:

(1) Availability, acceptability, and accessibility of existing (published or unpublished) vertical control in the region, including RTN networks.

(2) If GPS survey observations are required, the ability to use a CORS/OPUS elevation determination in lieu of observing extensive DGPS static baseline networks.

(3) Availability of expedited procedures for submitting bench mark descriptions and elevation data into the published NSRS, such as OPUS-based input methods.

d. The following paragraphs provide guidance on estimating the field survey scope required that will be needed to update a project datum to NAVD88 and, where applicable, publish the PPCP(s) for a project on the NSRS. These sections relate to the preference options listed in Table 3-5.

3-10. Utilizing Existing NSRS Control for USACE Primary Project Control PBMs. If published NSRS vertical control (Second Order or better) is available on or near a project, and at a density (spacing) adequate for supplemental topographic or geodetic surveying purposes (ideally well less than 15 miles distant from the project site, depending on available methods for surveying supplemental LPCPs), then there is effectively no need to establish a new NSRS primary project control reference point. These existing NSRS bench marks can be used to survey NAVD88 elevations on local control points (LPCPs) at the project site or to perform topographic or hydrographic survey operations—using standard topographic or geodetic survey methods, such as short-term static DGPS baseline observations, RTN/RTK techniques, differential leveling, total station traverse, etc. Optionally these LPCPs can be classified as PPCPs if they are positioned using one of the techniques listed in Table 3-5. The published NGS data for a PBM will be accepted as reliably connected to the NSRS after checks into one or more surrounding NSRS points. In effect, bench marks published by NGS on the NSRS will be accepted at "face value" after verification. If the NSRS bench mark does not have a horizontal position, this can be quickly obtained by a short-term CORS/OPUS observation. General criteria are shown in Table 3-6.

a. A recovered NGS NSRS bench mark will have some elevation uncertainty relative to the nationwide NSRS. Given limited USACE resources, it is not the intent of this guidance to investigate and minimize these published NSRS bench mark inaccuracies. It should be noted that existing NSRS bench mark elevations may have a greater relative uncertainty than elevations determined by height reductions based on recent GPS/CORS observations. In time, it is anticipated that all primary bench mark elevations will be observed and monitored relative to the nationwide CORS network.

Table 3-6. Recommended Criteria when Utilizing Published NSRS Control as the PPCP.

Check validity of published elevation	Yes
Nearby NSRS bench mark elevation check points	At least one – two recommended if feasible
Check survey tolerance between NSRS bench mark elevations	± 0.1 ft (± 3 cm) [1]
Survey elevation check methods	RTN/RTK, CORS/OPUS, differential levels, total station
NSRS input of check surveys	No
Recovery note on NSRS bench mark	Recommended—submit on-line to NGS or U-SMART
Horizontal position on vertical bench mark	Short term (< 2 hours) OPUS observation

[1] The acceptable tolerance between NSRS bench marks is project and site dependent, age of the marks, etc. Higher tolerances may be justified in some instances—use engineering judgment in determining acceptable tolerances.

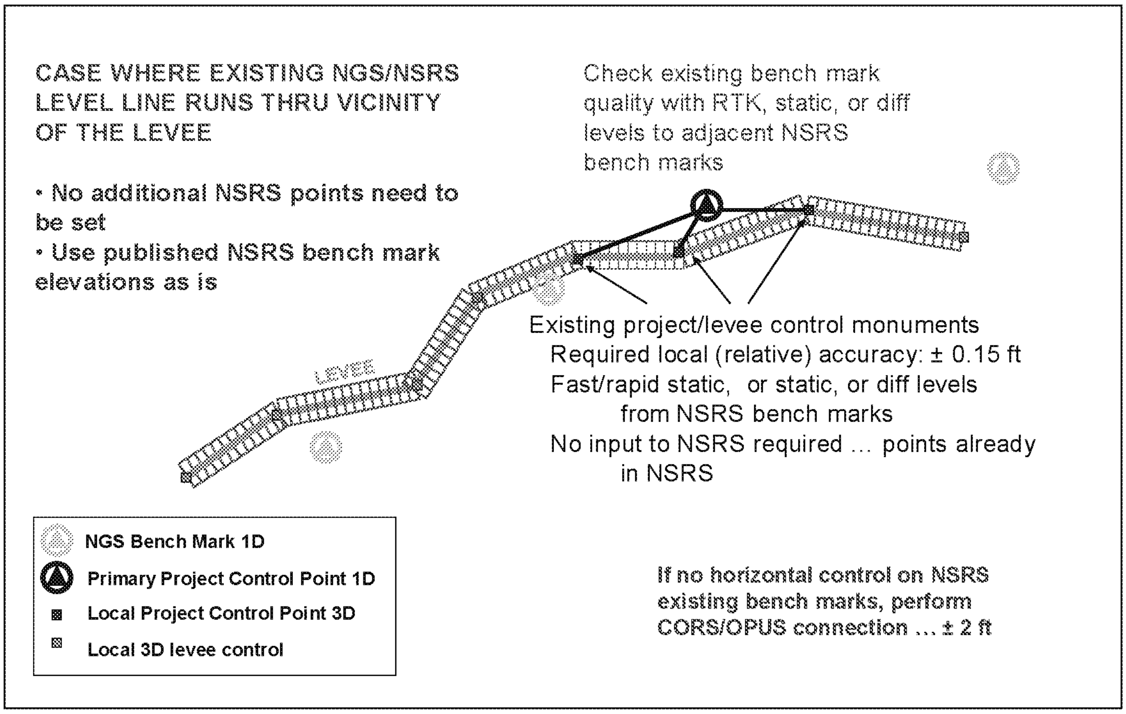


Figure 3-2. Published NSRS control within a levee project.

b. To illustrate a case where existing NSRS control can be used, Figure 3-2 shows a published NSRS line of levels running through a levee segment. In this case, the published NGS bench mark elevations will be accepted as the PPCP, and will be directly used for referencing NAVD88 elevations to supplemental LPCPs on the levee. No long-term static DGPS or CORS/OPUS observations will be required to adjacent points on the NSRS or CORS, other than a vertical tolerance check as indicated in Table 3-6. If the existing NSRS bench mark does not have published horizontal coordinates, a CORS/OPUS observation will provide a general horizontal reference for the PPCP.

c. The first step in evaluating NSRS coverage in a USACE project area is to access the NGS database and search for existing bench marks. This can be done graphically as shown in the screen capture in Figure 3-3. Alternatively, U-SMART can be used to view local NSRS points in a project area—see Figure 3-4. If a USACE levee system is located along a river system parallel with an NGS level line, then any of these bench marks can be directly used to provide NSRS (NAVD88) control on levee points—and only short-term RTN/RTK checks would be performed to confirm NSRS control accuracy and validity of the marks used as control. Per Table 3-6, a tolerance check between the NSRS bench marks of ± 0.1 ft would be considered reasonable.

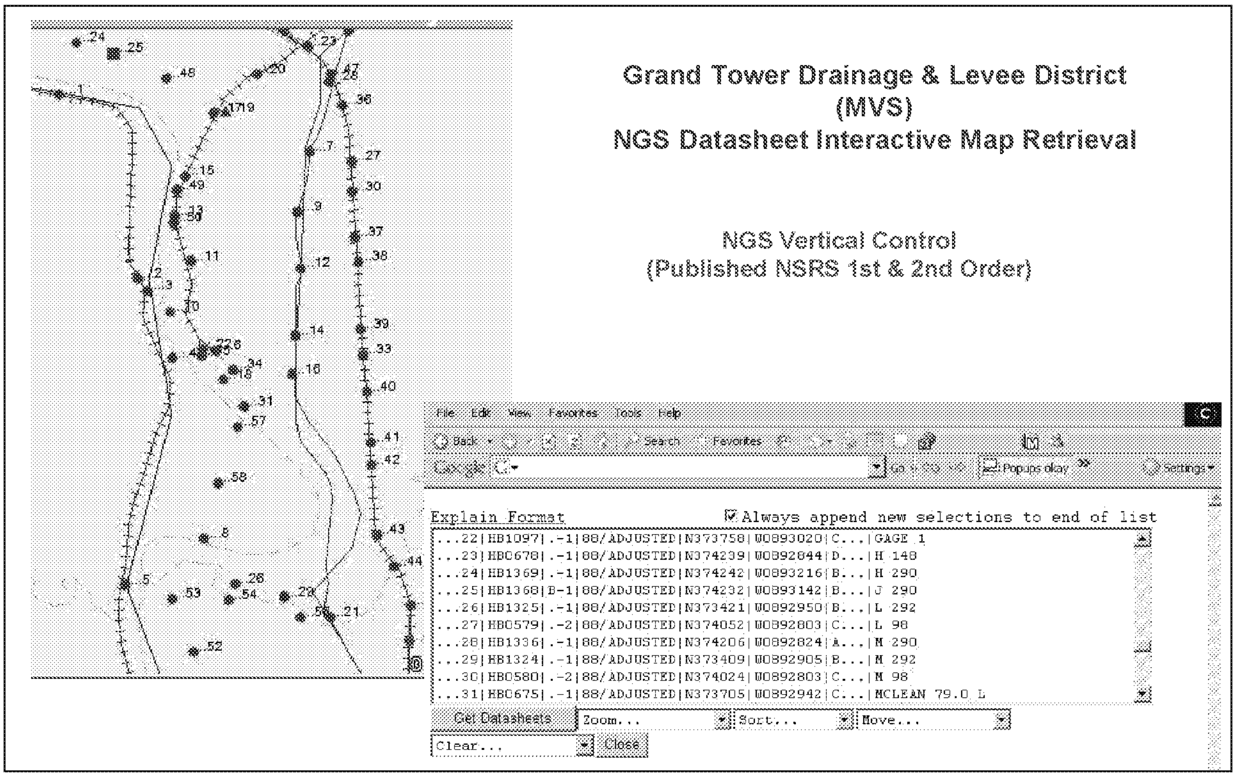


Figure 3-3. Survey control map from NGS web site.

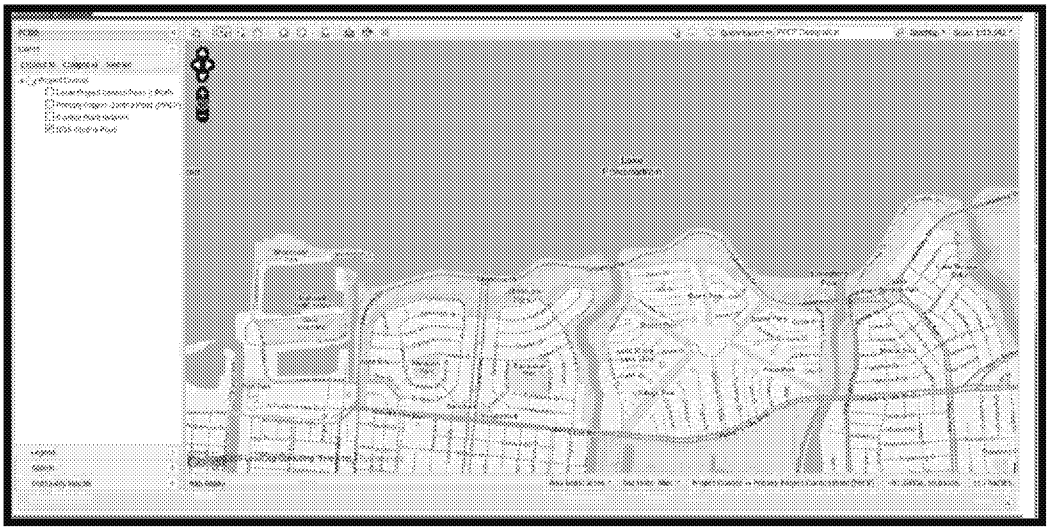


Figure 3-4. U-SMART map showing NSRS database points along Lake Pontchartrain shoreline.

3-11. CORS/OPUS Solutions for Primary Project Control Point Elevations. CORS/OPUS observations (Table 3-5 Preference [II]) will generally be the preferred survey method for relating USACE project control (PPCPs) to the NSRS. Static GPS observations are observed at a PBM relative to a network of CORS. The GPS observables are processed through OPUS and the PBM becomes part of the NSRS if descriptive data are forwarded to NGS—see Figure 3-5. CORS/OPUS solutions are a practical and efficient method of establishing primary project control to a vertical accuracy of ± 0.25 ft.

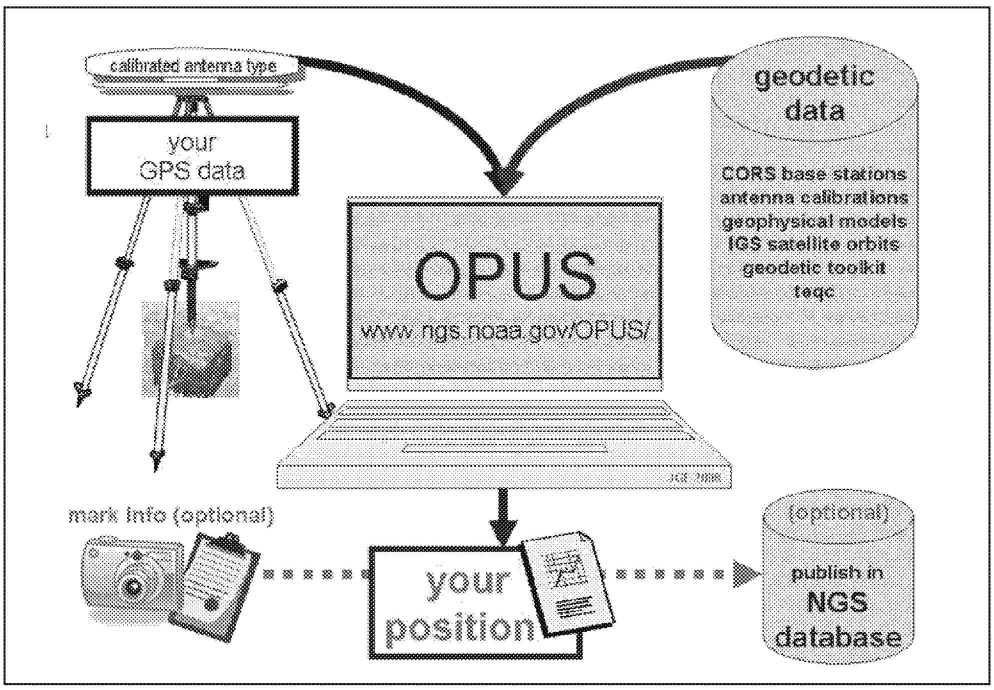


Figure 3-5. CORS/OPUS baseline processing and input to the NSRS database.

a. CORS/OPUS guidelines. When CORS/OPUS solutions are made to establish NAVD88 orthometric elevations on a PPCP, the NGS guidelines in Table 3-7 are recommended. These guidelines are current as of 2010—monitor the AGC and NGS web sites for future changes in these specifications. In the most populated regions in CONUS, CORS coverage is adequate for establishing NAVD88 orthometric elevations on PPCPs. These elevations usually can be obtained in less than one day with a one-man survey crew, and the resulting data can be efficiently input into the NSRS database using OPUS-based input procedures.

(1) CORS/OPUS observations for targeted ± 0.25 ft accuracies to the NSRS do not need to be pre-approved by the NGS; however, one should verify with NGS that the local geoid model is adequate to use to convert GPS ellipsoidal heights to orthometric heights. In most populated regions of CONUS where the NSRS vertical network is fairly dense, the geoid model should be adequate. In these areas, the geoid model accuracy is normally less than ± 3 cm and often closer to ± 1 cm. Thus, errors in the ellipsoidal-orthometric conversion will not be as significant. In mountainous areas or in high-subsidence regions, this may not be the case and NGS should be consulted in advance.

(2) In arriving at the estimated accuracy of a CORS/OPUS solution for an orthometric elevation, the error budget consists of (1) estimated accuracy of the geoid model, (2) the ellipsoid height measurement accuracy, and (3) base CORS station elevation accuracy. In many USACE Districts, < ± 5 cm estimated orthometric accuracies are currently being achieved. The OPUS Solution Report contains an estimate of the orthometric accuracy. Estimated orthometric accuracies exceeding ± 0.25 ft should not necessarily be rejected if "peak-to-peak" tolerances are acceptable. Especially note that valid CORS solutions exceeding some of the tolerances in Table 3-7 may be rejected for input to the NSRS.

Table 3-7. NGS Guidelines for CORS Ellipsoidal and Orthometric Elevation Measurements. (Primary Project Control Points -- ± 0.25 ft Orthometric Accuracy) [1]

Minimum number of CORS Stations within 200 miles	3
Minimum session time:	One ≥ 4-hour session required plus independent check session recommended. Total of two 4-hour sessions recommended [2]
Number of sessions	2 (see above)
Minimum observations	7,900
Observations used	> 70%
Ambiguities fixed	> 70%
Overall solution RMS	< 3 cm
HI measurements	Fixed height pole recommended; otherwise 3 measurements required in different units
Ephemeris	IGS precise or rapid (available next day)
Maximum Peak-to-Peak tolerances (ellipsoidal):	
Horizontal	< 4 cm
Vertical	< 8 cm
Geoid model	OPUS determined
Geoid model--estimated accuracy at site	NTE 3 cm (check w/NGS)
Data processing and NSRS database input	NGS OPUS-based

Table 3-7 (Concluded). NGS Guidelines for CORS Ellipsoidal and Orthometric Elevation Measurements. (Primary Project Control Points -- ± 0.25 ft Orthometric Accuracy) [1]

Notes:

[1] Some exceptions to the tolerances in these guidelines may be warranted in certain cases; however, a USACE acceptable CORS solution may be rejected for NSRS input. These guidelines are periodically being updated by NGS—they are current as of 2010. Contact AGC or the NGS OPUS web site for subsequent changes and updates.

[2] Since the purpose of the second 4-hour session is used as a check, other methods such as the use of RTN or RTK methods may be used to verify and check the first 4-hour observation. In remote areas it is still recommended that a second 4-hour observation session be done to eliminate the need to travel back to the site if the first 4-hour observation does not meet the requirements.

c. Sample OPUS Solution Report. Figure 3-6 below is an example of a 19-hour OPUS observation at a NOAA tidal bench mark in Georgia. The report statistics indicated the criteria in Table 3-7 were met. (Applicable assessment criteria that should be reviewed in the report are shown as bolded). Note that the 2.0 cm orthometric height accuracy is "peak-to-peak"—not the NSRS relative accuracy estimate.

Figure 3-6. Sample OPUS Solution Report.

```
9511 TIDAL F  [NOAA Tide Gage 867 9511 - Kings Bay, GA - Jacksonville District]
FILE: 71650290.09o 000105225

                              NGS OPUS SOLUTION REPORT
                              ========================

All computed coordinate accuracies are listed as peak-to-peak values.
For additional information: http://www.ngs.noaa.gov/OPUS/about.html#accuracy

      USER: damon.a.wolfe@usace.army.mil            DATE: May 05, 2010
RINEX FILE: 7165029a.09o                            TIME: 18:53:30 UTC


  SOFTWARE: page5  0909.08 master2.pl 0810233      START: 2009/01/29 00:01:00
 EPHEMERIS: igs15164.eph [precise]                  STOP: 2009/01/29 19:15:30
  NAV FILE: brdc0290.09n                        OBS USED: 48669 / 51797   :94%
  ANT NAME: TRM_R8_GNSS     NONE             # FIXED AMB:   259 /   293   :88%
ARP HEIGHT: 1.75                             OVERALL RMS: 0.017(m)
```

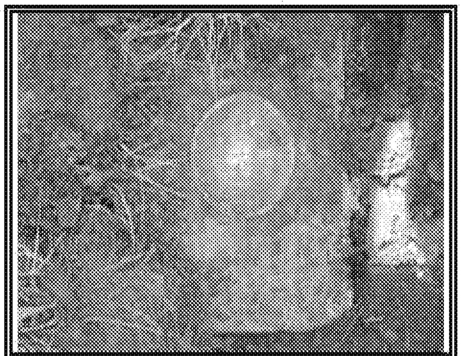
Figure 3-6 (Concluded). Sample OPUS Solution Report.

```
REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)            ITRF00(EPOCH:2009.0778)

         X:       808781.729(m)   0.013(m)           808781.030(m)   0.013(m)
         Y:     -5423271.976(m)   0.018(m)         -5423270.449(m)   0.018(m)
         Z:      3247037.568(m)   0.014(m)          3247037.378(m)   0.014(m)

       LAT:   30 48  6.91976      0.016(m)        30 48  6.94129     0.016(m)
     E LON:  278 28 55.57376      0.014(m)       278 28 55.55623     0.014(m)
     W LON:   81 31  4.42624      0.014(m)        81 31  4.44377     0.014(m)
    EL HGT:         -24.719(m)    0.014(m)              -26.202(m)   0.014(m)
 ORTHO HGT:           3.788(m)    0.020(m) [NAVD88 (Computed using GEOID09)]

                        UTM COORDINATES    STATE PLANE COORDINATES
                         UTM (Zone 17)         SPC (1001 GA E)
Northing (Y) [meters]     3407764.931           89071.578
Easting (X)  [meters]      450456.269          262082.476
Convergence  [degrees]    -0.26520537          0.33222763
Point Scale                0.99963028          0.99994753
Combined Factor            0.99963416          0.99995141

US NATIONAL GRID DESIGNATOR: 17RMQ5045607764(NAD 83)

                              BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE
DISTANCE(m)
DE6005 GNVL GAINESVILLE CORS ARP           N294111.557 W0821636.736  143609.7
DJ6111 SAV5 SAVANNAH 5 CORS ARP            N320818.937 W0814146.790  149170.2
DK4049 GASK SKIDAWAY ISLAND CORS ARP       N315915.255 W0810122.431  139632.1

                 NEAREST NGS PUBLISHED CONTROL POINT
BC2560      H 62 06                        N304808.555 W0813108.247     113.4

Horizontal network accuracy =    0.00212 meters.
Vertical network accuracy   =    0.00228 meters.

  STATE PLANE COORDINATES - U.S. Survey Foot
         SPC (1001    GA E)
Northing (Y) [feet]        292229.003
Easting  (X) [feet]        859848.923
Convergence  [degrees]     0.33222763
Point Scale                0.99994753
Combined Factor            0.99995141
```

b. CORS/OPUS data submittal and NSRS publication. The guidelines in Table 3-7 must be followed in order to meet NGS QC and QA criteria for inputting CORS-derived bench mark elevations into the NSRS. The NGS publishes detailed procedures on their web site for submitting CORS/OPUS GPS observations and publishing station data in the NSRS database. A published PPCP datasheet processed through the OPUS database input system to the NSRS is shown in Figure 3-7.

SURVEY DATASHEET (Version 1.0)

PID: BBBS37
Designation: USACE V-LOWPAP-4
Stamping: V-LOWPAP-4 2K9
Stability: Monument will probably hold position well
Setting: Object surrounded by mass of concrete
Description: This monument is used to comply with the Comprehensive Evaluation of Project Datum (CEPD) initiative. This monument is a standard USACE Brass Cap set atop a 5/8" rebar in concrete. This point is +/- 10 feet southerly from the southerly edge of a pedestrian walkway attached to the Cass Street bridge crossing the Big Papillion Creek. The point is located on the left bank of said creek and is marked with a White Carsonite Post.
Observed: 2009-08-06T18:01:00Z
Source: OPUS - page5 0909.08



Close-up View

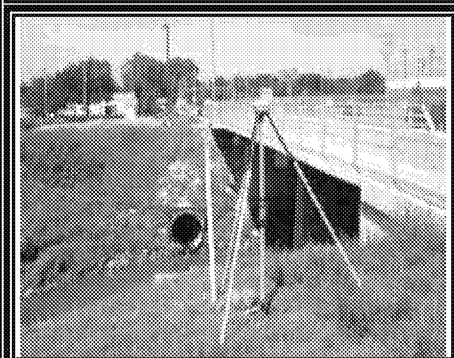
REF_FRAME: NAD_83 (CORS96)	EPOCH: 2002.0000	SOURCE: NAVD88 (Computed using GEOID03)	UNITS: m	SET PROFILE	DETAILS

LAT:	41° 15' 47.39187"	± 0.035 m
LON:	-96° 2' 9.04502"	± 0.020 m
ELL HT:	290.587	± 0.034 m
X:	-504889.732	± 0.024 m
Y:	-4774966.285	± 0.034 m
Z:	4184627.958	± 0.029 m
ORTHO HT:	318.019	± 0.049 m

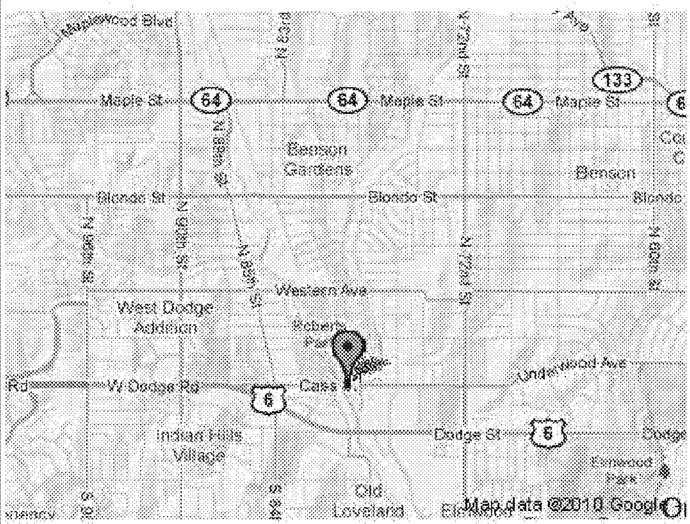
	UTM 14	SPC 2600(NE)
NORTHING:	4572209.641m	166359.449m
EASTING:	748310.334m	831967.948m
CONVERGENCE:	1.95591174°	2.62703272°
POINT SCALE:	1.00035890	0.99966752
COMBINED FACTOR:	1.00031330	0.99962196

CONTRIBUTED BY

david.d.salter
US Army Corps of Engineers



Horizon View



The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

Figure 3-7. OPUS processed data sheet of a USACE PPCP. (Omaha District)

3-12. <u>GPS Static Baseline Specifications for Networking Primary Project Control Point Connections to the NSRS</u>. This section describes specifications to be used when CORS/OPUS solutions cannot be made (Preference [III] in Table 3-5) and networked static baseline observations must be observed and adjusted. Table 3-8 outlines the recommended GPS observing specifications needed to determine NAVD88 elevations relative to the NSRS based on a target accuracy of ± 0.25 ft. The DGPS static baseline observing specifications for network connections in Table 3-8 are largely tailored around current USACE EM 1110-1-1003 (*NAVSTAR GPS Surveying*) and NGS orthometric height guidelines for 2 cm to 5 cm accuracy orthometric network densification — *Guidelines for Establishing GPS Derived Orthometric Heights* (NOAA 2005). These GPS orthometric height guidelines in Table 3-8 have been modified to fit the nominal ± 0.25 ft accuracy requirements in Table 3-1.

a. GPS survey specifications. The following network connection specifications in Table 3-8 are intended to achieve the nominal target accuracy requirements for USACE primary project control. This is not to say that they will work in all cases, or in all locations, due to a variety of factors too numerous to list here. The bottom line is that on-site baseline reduction and processing software should readily (i.e., same or next day) identify the quality of the results from a constrained network adjustment statistical summary.

b. Data submittal to NSRS via Blue Book procedures. When OPUS-based NSRS submittal methods cannot be utilized, GPS observations and leveling observations to newly established PPCPs must be adjusted and submitted to the NSRS using NGS Blue Book procedures—"*Input Formats and Specifications of the National Geodetic Survey (NGS) Data Base*" (NOAA 1994). The Blue Book is a guide for preparing and submitting geodetic survey data for incorporation into the NSRS database. NOAA 1994 provides overall instructions and a checklist for submitting raw data, vector solutions, project and station data, station descriptions, applicable horizontal and vertical connections, least squares adjustments, a project sketch, and a project report. Additional guidance, tutorials, and required software are referenced therein with web addresses for downloading. It is recommended that the A-E performing the field surveys work directly with other firms that have an established record for producing accepted Blue Book submittals to ensure proper procedures and documentation are followed throughout the project.

c. Resultant accuracy estimates. Since the specifications in Table 3-8 have been modified from the NOAA 2005 specifications to meet USACE project orthometric accuracy requirements, it is important that published NSRS data sheets contain a statement to that effect. Including the estimated orthometric accuracy from the constrained network adjustment in that statement would be warranted.

Table 3-8. USACE Guidelines for Establishing GPS-Derived ± 0.25 ft Accuracy Orthometric Elevations on PPCPs using GPS Network Connections to NSRS Bench Marks.

Occupation time based on baseline distance to nearest two NSRS bench mark(s):

Distance	Time
< 20 km	30 min
20-40 km	60 min
40-60 km	180 min
60-80 km	240 min
80-100 km	300 min
> 100 km	> 5 hours

NGS pre-approval required	Yes (local NGS advisor, HQNGS, or NGS web site)
Number of days station occupied:	1 day (perform interim break-down and reset)
Dual-frequency receiver required:	Yes
NGS modeled geodetic quality antenna :	Yes (ground plane recommended)
Minimum number of observations per baseline:	2
Fixed-height tripods/poles:	Required
Satellite altitude mask angle (minimum):	10 degrees (collect) 15 degrees (process)
Maximum allowable VDOP:	5
Precise ephemeris:	Recommended, but not required
Geoid model:	Most recent
Add CORS baselines to adjustment:	Yes
Maximum distance to CORS points:	No restriction—weight accordingly with local NSRS baselines
NSRS input:	Blue Book or OPUS-based input

Table 3-8 (Concluded). USACE Guidelines for Establishing GPS-Derived ± 0.25 ft Accuracy Orthometric Elevations on PPCPs using GPS Network Connections to NSRS Bench Marks.

Notes:

Static (networked) DGPS baseline connections may be required in cases where the current geoid model has unacceptable accuracies in a particular region, such as in sparsely NSRS controlled mountainous areas, or in places where CORS stations are too distant—greater than 200 miles. Regardless, CORS baselines will be used in the adjustment if available.

DGPS network connection procedures will require considerably more field effort and must follow the guidelines in Table 3-8. Inputting networked DGPS observation data into the NSRS will currently require "Blue Booking." However, it is expected that an alternate "Blue Booking" methods (i.e., OPUS) eventually will be available from NGS for adjusting traditional networked data and inputting results into the NSRS.

At least two baselines tied to or "networked" with nearby NSRS points should be observed. These local baselines will be combined with CORS baselines, and adjusted using NGS software routines.

Proposed observation schemes for networked baseline observations to nearby NSRS points shall be pre-approved by NGS. Pre-approval may be obtained from the local NGS geodetic advisor or from designated NGS HQ staff. The format for submitting proposed schemes should follow the "Project Proposal Form" available from the NGS.

3-13. The USACE Survey Monumentation Archival and Retrieval Tool (U-SMART). The U-SMART system, a fast and user-friendly web-based system (Figure 3-8), facilitates compliancy with the requirement to link the proper geodetic, hydraulic, tidal, and legacy control to their respective projects. Each project is required to have a minimum of 3 control points, one of which must be directly connected to and included in the NSRS. These control points must also be connected to the local water surface datum/model used for engineering designs and studies. U-SMART provides the tools to link local control networks together and link the project to the appropriate gage and the local legacy control points used for deformation studies and historical surveys.

a. U-SMART running as part of the web-based CorpsMap system serves as the liaison between USACE project control and the NGS/NSRS database. The U-SMART system continually monitors the NGS database looking for spatial changes, and alerts the user of required updates to local control. Benefits of U-SMART include:

(1) Common source for all project control.

(2) No desk drawer control files or duplicates.

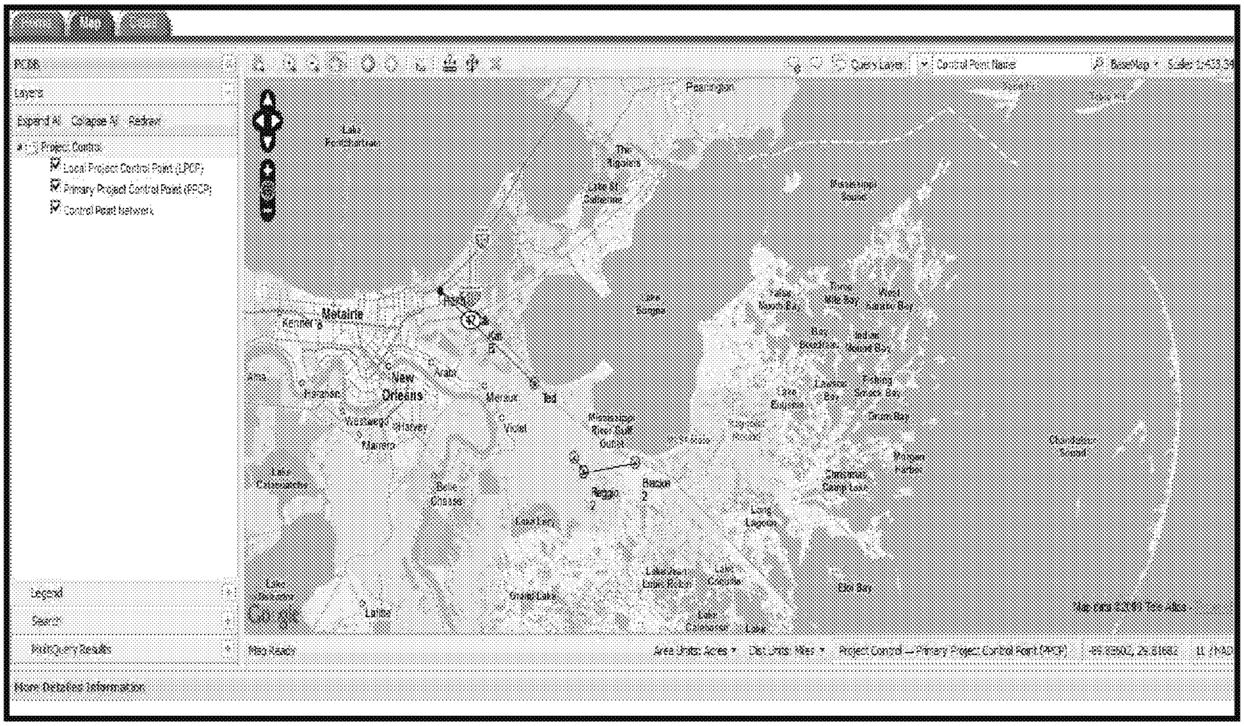


Figure 3-8. U-SMART web-based map interface indicating PPCPs and LPCPs.

(3) Entire District on same page.

(4) Compares coordinates against NGS database.

(5) Links project control to authorized projects.

(6) Links primary control to local project control networks.

(7) Minimized maintenance at the local level.

(8) Easy archival and retrieval.

b. Many USACE districts already have in place a system for archiving geodetic control which requires development, maintenance, and storage space. Many of these systems are not publicized, which limits their effectiveness in providing the common source of control information to USACE customers. Some districts with large resources have developed comprehensive systems to capture their survey control data while other districts with limited resources are still using hard copies in the old file cabinets. The 1990s vintage "SEMMS" control database system attempted to provide a national platform for USACE survey control; however, only a handful of districts are currently using it. It is critical that the data contained in the district's archives be maintained and available for designers, planners, and engineers to access. With a U-SMART central repository for USACE survey control, it is less likely that the wrong survey control will be used.

c. The Control Point Description Form (Figure 3-9) is used to input horizontal and vertical coordinates, images, and other information about the PPCPs and LPCPs in the U-SMART database. The form is a simple PDF document that allows the user to populate the appropriate fields depending on the purpose of the submittal. The form has several flavors and can be used for documenting newly established points, recovery notes, entering historical information on the mark such as local/legacy coordinates, and can also be used to edit existing information in the database. Easy to populate pulldowns, checkboxes, and radio buttons simplify the process of data entry. Maps, pictures, and images are also captured and archived with the form. Once the form is completed, the data is imported into U-SMART by the District Datum Coordinator or a representative with the delegated responsibility to insure the quality of the information.

d. For additional information on U-SMART contact the Army Geospatial Center. See the web link in Chapter 1.

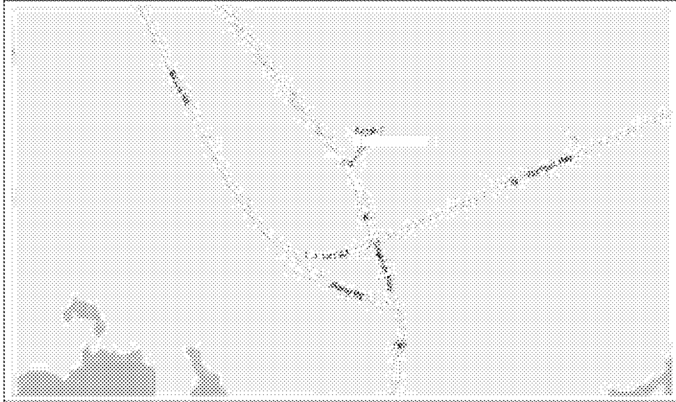
3-14. Methods for Determining the Relationship between Legacy Project Datums and NAVD88. Many of the legacy reference datums on USACE flood risk management projects, hurricane protection projects, river gages, reference pools, flow lines, flood stage, etc, are not referenced to the federal NSRS, and as such cannot be easily incorporated into hydrologic, hydraulic, flood inundation, and risk assessment models, or related to regional reference datums being used by other local, state, and federal agencies In CONUS the methodology used to shift historical or legacy survey data (e.g., NGVD29) to NAVD88 will vary depending upon many factors such as time, funding, accuracy requirements, etc. The most accurate and costly method is to re-observe each bench mark used for an old survey of interest. Even with the establishment of new elevations we can only estimate the changes that have taken place between then and now. The relationship between the surveyed features and the control marks may have also changed due to subsidence, settlement, or NSRS readjustments.

a. General. Transforming between legacy NGVD29 and NAVD88 is not straightforward, given NGVD29 has not been supported or updated by NGS since it was superseded in the early 1990s; thus, elevations still referenced to NGVD29 can have unacceptable vertical errors. Models have been developed for performing general "mapping grade" transformations from NGVD29 to NAVD88. These models (e.g., VERTCON and CORPSCON) were not intended to provide survey or construction quality accuracy, and must be used with caution given they are only coarse estimates. Floodwall or levee flood protection elevations should not be designed, constructed, or certified based on uncertain transformations from NGVD29 using CORPSCON.

b. Datum transform methods. Generally there are four methods to determine the datum/epoch shift. It is important to maintain the historical project files and source documents documenting what datum was used when, and how the project datums were derived. This is usually detailed down to the individual bench mark level of detail, documenting what bench marks were used and what elevations were used. Whichever method is used, transformations all have various elevation uncertainties, and it is important to have knowledge of the uncertainties of the final elevations used.

USACE Survey Marker Archive & Retrieval Tool Datasheet Type: New

Designation: Reggio 2
Project: MRGO
Stamping: Reggio 2
PID NGS: AT0804 COE:
State: Louisiana
County: St. Benard
District New Orleans
Nearest Town: Reggio
USGS Quad:
T.R.S.:
Nearest Hwy/Mi:
B/L Sta/Off:
Date Recovered: May 2007
By: Chustz
Condition/Stability: Good D
Setting/Monument Type: SS Rod
Owner:
GPS Suitable: (•) Yes ( ) No
Obstructions: [ ] N [ ] E [ ] S [ ] W



- Horizontal -
Datum: NAD83 (2002.00)
Lat: 29 50 30.71876 N
Lon: 89 45 32.43138 W
Local Accuracy: 1-cm
NSRS Accuracy: 2-cm
Survey/Computation Method:
Static GPS Network
Date Observed: Sep 1, 2009

- Vertical -
Datum: NAVD88 (2004.65)
Elevation Ht: 4.9
Ellip Ht: -79.163 Ft
Local Accuracy: 2-cm
NSRS Accuracy: 5-cm
Survey/Computation Method:
Static GPS Network
Date Observed: Sep 16, 2007 Geoid03

Description/Comments:
The station is 25.0 ft. northeast of centerline of north bound lanes of hwy, 3.6 ft. North from north end of a bridge concrete rail, 2.1 ft. northeast of a concrete curb and 1.5 ft. northwest of a concrete abutment wing. Station is a stainless steel rod accessed through a logo cap stamped- reggio2 1987, flush with top of logo sleeve cover missing otherwise in good condition.

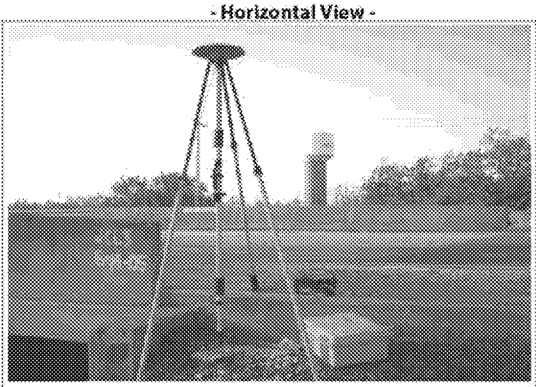
Access: open

- Tidal/Hydraulic Gauge Relationships -
Owner/Code: USACE
Gauge ID: 56123 Epoch: 83-01

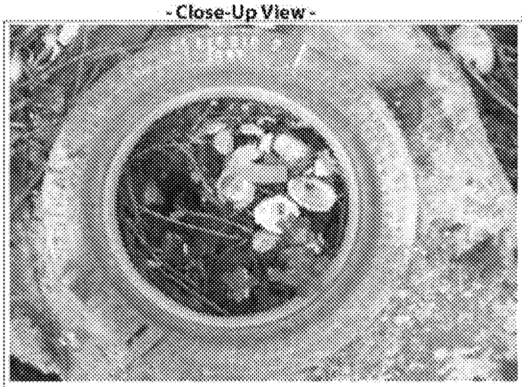
- Datum -	- Elevation -
LMSL	0.51
MLLW	-0.02
Select	
Select	

Zone: Northing: Easting: Convergence: CSF:

- Horizontal View -



- Close-Up View -



Required Fields in Red [Reset Form] [Submit] U-SMART ver 1.1
9/24/2009

Figure 3-9. Sample U-SMART datasheet at a PPCP. (New Orleans District)

(1) Field Measurements with Known Historical Elevation(s). This method will yield the most accurate values based on the historical reference bench marks. The reference bench marks will need to be recovered and occupied/surveyed using CORS/OPUS, RTN, RTK, or other methods, depending upon required accuracy. The difference between the legacy elevation used for the original survey and the NAVD88 elevation established from the new network will directly tie in the old work to the latest control. This will not account for relative differences between the project control and the project features, to include any differential subsidence or settlement that may have occurred after the legacy reference datum was established.

(2) Field Measurements without Known Historical Elevation(s). When the reference bench mark legacy datum has not been documented and unknown, some assumptions will be required, such as what bench mark was used and what its elevation was. Again, CORS/OPUS, RTN, RTK, or other methods depending upon required accuracy may be used to establish a new elevation on the reference mark. The historical elevation will have to be assumed based on what was available at the time of design. The difference between the assumed historical elevation and the newly established elevation will be used to shift the survey to the new datum/epoch.

(3) Common Published Marks in Survey Area. When time and money are constraints, the closest marks with published elevations in both datum/epochs can be used to determine an average shift for the area. This method contains many assumptions and therefore is the less accurate and contains more uncertainty but may be of use on some projects.

(4) CORPSCON or VERTCON conversions between NGVD29 and NAVD88. These conversions are approximate and do not account for subsidence or the changes in elevation from epoch to epoch. The conversion models were constrained to the published elevations at the time the conversion model was created (ca 1990). These models contained errors associated with the already deteriorating NGVD29 elevation accuracies in 1990. These methods should not be used for anything other than a simple datum shift, keeping in mind that subsidence is not accounted for.

c. FEMA guidance for converting to NAVD88. Appendix B in FEMA's "Guidelines and Specifications for Flood Hazard Mapping Partners" (FEMA 2003) contains standards and criteria for converting between NGVD29 and NAVD88 datums, including guidance for the conversion of unrevised flood elevations. These conversion standards are largely based on CORPSCON and VERTCON procedures. Methods for computing average datum conversions over a FIRM study region are defined. Maximum conversion tolerances of ± 0.25 ft are prescribed in this FEMA guidance.

3-15. <u>Summary of USACE Survey Standards for Connecting Projects to Nationwide Reference Datums</u>. Table 3-9 summarizes the recommended procedures and standards covered in this manual for connecting projects to the NSRS.

Table 3-9. Summary of Recommended Survey Standards for Referencing Grade Elevations on Navigation Projects, Multipurpose Projects, Levees, Floodwalls, and Related Retaining Structures.

	Inland Flood Protection & Navigation Projects [Rivers, lakes, reservoirs, pools, Great Lakes]	Coastal Hurricane & Shore Protection Projects Coastal Navigation Projects
Reference Datums:		
Hydraulic Reference Datum [1]	LWRP, pool, etc. (stage, flood profile) Hydraulically modeled from gages	Local MSL or Local MLLW (stillwater, surge, etc) Hydrodynamically modeled from NOAA tide gages
Geodetic (Orthometric) Reference Datum [1]	NOAA NSRS (NAVD88)	NOAA NSRS (NAVD88)
High subsidence or crustal uplift areas	NOAA Time Dependent Reference Network	NOAA Time Dependent Reference Network
Ellipsoid Reference Datum [Optional/Recommended Reference]	GRS80 (NAD83 NSRS)	GRS80 (NAD83 NSRS)
Legacy Geodetic or Tidal Datums	Sea Level, NGVD29, Cairo, MSL 1912, etc. Define relationship to NAVD88	MLW, Mean Low Gulf, Cairo, etc. Define relationship to NOAA Local MSL or Local MLLW

[1] The relationship between these two datums must be physically determined at PBM reference points and mathematically modeled throughout the project area.

Table 3-9 (Continued). Summary of Recommended Survey Standards for Referencing Grade Elevations on Navigation Projects, Multipurpose Projects, Levees, Floodwalls, and Related Retaining Structures.

	Inland Flood Protection & Navigation Projects [Rivers, lakes, reservoirs, pools, Great Lakes]	Coastal Hurricane & Shore Protection Projects Coastal Navigation Projects
Primary Project Control Points (PPCPs):		
Primary PBM published in NSRS	Yes	Yes (NOAA CO-OPS database if applicable)
Minimum PBMs required per project/segment	1	1
Spacing of primary PBMs NTE	15 – 20 miles (see Chapter 6)	15 - 20 miles (see Chapters 4 and 5)
Recommended min vertical accuracy	± 0.25 ft relative to NSRS	± 0.25 ft relative to NSRS
High subsidence or uplift areas	± 0.15 ft relative to NSRS	± 0.15 ft relative to NSRS
Recommended min horizontal accuracy (for mapping/GIS applications only)	± 2 ft relative to NSRS—NAD83	± 2 ft relative to NSRS—NAD83
GPS ellipsoid height observation at PPCP	Recommended	Recommended

Table 3-9 (Continued). Summary of Recommended Survey Standards for Referencing Grade Elevations on Navigation Projects, Multipurpose Projects, Levees, Floodwalls, and Related Retaining Structures.

	Inland Flood Protection & Navigation Projects [Rivers, lakes, reservoirs, pools, Great Lakes]	Coastal Hurricane & Shore Protection Projects Coastal Navigation Projects
Water Level Gages: [2]		
Primary gage reference PBM connected to	NSRS (NAVD88)	NSRS and NOAA CO-OPS tidal network
Minimum number of reference PBMs at gage	3	5 (NOAA tide gage)
Primary reference PBM metadata repository	NSRS and/or U-SMART	NSRS & NOAA CO-OPS database; U-SMART
Periodic gage inspection metadata repository	NSRS and/or U-SMART	NSRS & NOAA CO-OPS database; U-SMART
Update low water or tidal datums	per Division/District H&H requirements	per NOAA published revisions (typically 19 years, or 5 years in high subsidence areas)

[2] See Chapter 4 for additional details

Table 3-9 (Continued). Summary of Recommended Survey Standards for Referencing Grade Elevations on Navigation Projects, Multipurpose Projects, Levees, Floodwalls, and Related Retaining Structures.

	Inland Flood Protection & Navigation Projects [Rivers, lakes, reservoirs, pools, Great Lakes]	Coastal Hurricane & Shore Protection Projects Coastal Navigation Projects
RECOMMENDED STANDARDS:		
Local Project Control Points (LPCPs) for Design & Construction:		
PBMs spaced	as required	as required
Reference datum and/or NOAA tidal	Primary project control (NSRS)	Primary project control (NSRS)
Minimum number of PBMs for construction contract plans & specifications	3	3

Table 3-9 (Concluded). Summary of Recommended Survey Standards for Referencing Grade Elevations on Navigation Projects, Multipurpose Projects, Levees, Floodwalls, and Related Retaining Structures.

	Inland Flood Protection & Navigation Projects [Rivers, lakes, reservoirs, pools, Great Lakes]	Coastal Hurricane & Shore Protection Projects Coastal Navigation Projects
Site Plan Topography Accuracies:		
Reference datum	Local project PBM control	Local project PBM control
Hard topographic features: Floodwall cap elevations, culverts, inverts, first floors, boring references, etc.	± 0.3 ft	± 0.3 ft
Ground shots on levee (profiles or cross-sections)	± 0.5 ft	± 0.5 ft
Floodplain topography (general mapping)	± 0.5 ft to ± 2 ft relative to NSRS	± 0.5 ft to ±2 ft relative to NSRS
Construction stake out—set hubs to	± 0.01 to 0.05 ft	± 0.01 to 0.05 ft

CHAPTER 4

Procedures for Referencing Datums and Dredging Grades on Coastal Navigation Projects

4-1. General. This chapter provides guidance on evaluating and establishing vertical reference grades on coastal navigation projects in tidal waters. It covers the procedures needed to ensure these projects are adequately referenced and modeled relative to the National Water Level Observation Network (NWLON) tidal datum and the National Spatial Reference System (NSRS) orthometric datum established by the Department of Commerce as outlined in Chapter 1 and ER 1110-2-8160. It also covers the tidal gaging and modeling methods used to define the varying MLLW datum plane at a project site, including NOAA's recently developed "VDatum" software tool that transforms vertical navigation datums throughout CONUS coastal regions. This chapter also discusses real-time GPS/RTN survey methods that are employed to measure the local water surface elevation relative to the MLLW datum. Much of the guidance in this chapter is also applicable to hurricane and shore protection projects covered in Chapter 5.

a. Scope. In coastal areas, and in coastal inlets, accurately modeling and measuring the varying tidal datum plane (e.g., LMSL or MLLW) relative to NAVD88 and the NAD83/GRS80 ellipsoid is the challenge. Measurement of the elevation of the actual water surface relative to the tidal reference datum must be done accurately in order to determine the acoustically surveyed depth/elevation of a point relative to the tidal datum. This water surface elevation varies temporally due to tidal phase latencies, tidal currents, and meteorological effects such as wind. This chapter provides procedural information and guidance to ensure survey and dredge positioning systems are effectively compensating for these tidal variations and other effects in coastal regions and inland rivers subject to fresh water flow and tidal influence. Non-tidal inland river, pool, reservoir, and lake datums are covered in Chapter 6.

b. Requirements to reference coastal navigation projects to NOAA MLLW datum. In accordance with the intent of Section 224 of WRDA 1992 and "The National Tidal Datum Convention of 1980" (NTDC 1980), navigation projects in coastal tidal areas must be defined relative to the datum shown on official NOAA navigation charts and NOAA tidal predictions for the project area. The WRDA 1992 amendment to Section 5 of the Rivers and Harbors Appropriation Act of 1915, which is excerpted below, supersedes previously authorized reference datums (e.g., Mean Low Water on Atlantic and Gulf coasts), and specifically directs that the datum defined by the U.S. Department of Commerce be used.

> *Section 5 of the Act of March 4, 1915 (38 Stat. 1053; 33 U.S.C. 562), is amended -- (as indicated). "That in the preparation of projects under this and subsequent river and harbor Acts and after the project becomes operational, unless otherwise expressed, the channel depths referred to shall be understood to signify the depth at mean lower low water as defined by the Department of Commerce for nautical charts and tidal predictions in tidal waters tributary to the Atlantic and Gulf coasts and at mean lower low water as defined by the Department of Commerce for nautical charts and tidal predictions in tidal*

waters tributary to the Pacific coast and the mean depth for a continuous period of fifteen days of the lowest water in the navigation season of any year in rivers and nontidal channels, and after the project becomes operational the channel dimensions specified shall be understood to admit of such increase at the entrances, bends, sidings, and turning places as may be necessary to allow of the free movement of boats.

USACE projects that are still defined relative to non-standard or undefined legacy datums (e.g., Mean Low Gulf (MLG), Gulf Mean Tide, MSL, NGVD, MLW, COEMLW, etc.) should have technically valid transforms to the NOAA MLLW chart/tidal datum for the area. In isolated cases, the legacy datum may be retained as the reference grade provided its relationship to NOAA MLLW datum is accurately defined based on current gage data at the project site. In such projects, depth data furnished to NOAA and other project users must indicate the primary reference gage, along with the tidal datum epoch period and the relationship between the legacy datum, NOAA MLLW, and NAVD88. Legacy "Low Water" datums must be periodically updated for sea level change and regional subsidence using similar computational techniques established by NOAA for coastal waters. Refer to Appendix C for additional details on referencing coastal projects to the federal MLLW datum.

c. References. This chapter does not cover the detailed theory, principles, and computational procedures for establishing tidal datums from observed gage data, or for performing hydrodynamic tidal modeling of navigation projects. For more technical information on these topics consult the USACE and NOAA technical publications listed in Appendix A.

4-2. Overview of Procedures Needed to Reference Grades on Navigation Projects. Figure 4-1 illustrates the various datum relationships that will need to be established to ensure a navigation project complies with the requirements in ER 1110-2-8160. Actions to develop these relationships are summarized below. Subsequent sections in this chapter detail specific procedures for each of these actions.

a. Primary Project Control Point (PPCP) reference. Designate a NSRS published PPCP(s) needed to position survey and dredging operations over the project reach using RTK techniques. The PPCP shown in Figure 4-1 provides RTK coverage over the entire project reach. Alternatively, a RTN may be utilized, provided that it is "site-calibrated" to NSRS tidal bench marks. The PPCP should have horizontal coordinates (NAD83) of sufficient accuracy ($< \pm 2$ ft relative to the NSRS) to position survey and dredging operations. As shown in the figure, the PPCP provides the relationship between NAVD88, NAD83/GRS80 ellipsoid, MSL, and the Geoid (geoid height), and perhaps a legacy datum such as NGVD29. Its vertical accuracy ($< \pm 0.25$ ft relative to NAVD88) is usually adequate for RTK initialization; site calibration being performed relative to the NOAA tidal gage reference bench marks shown in Figure 4-1. Further details are covered in Section 4-3.

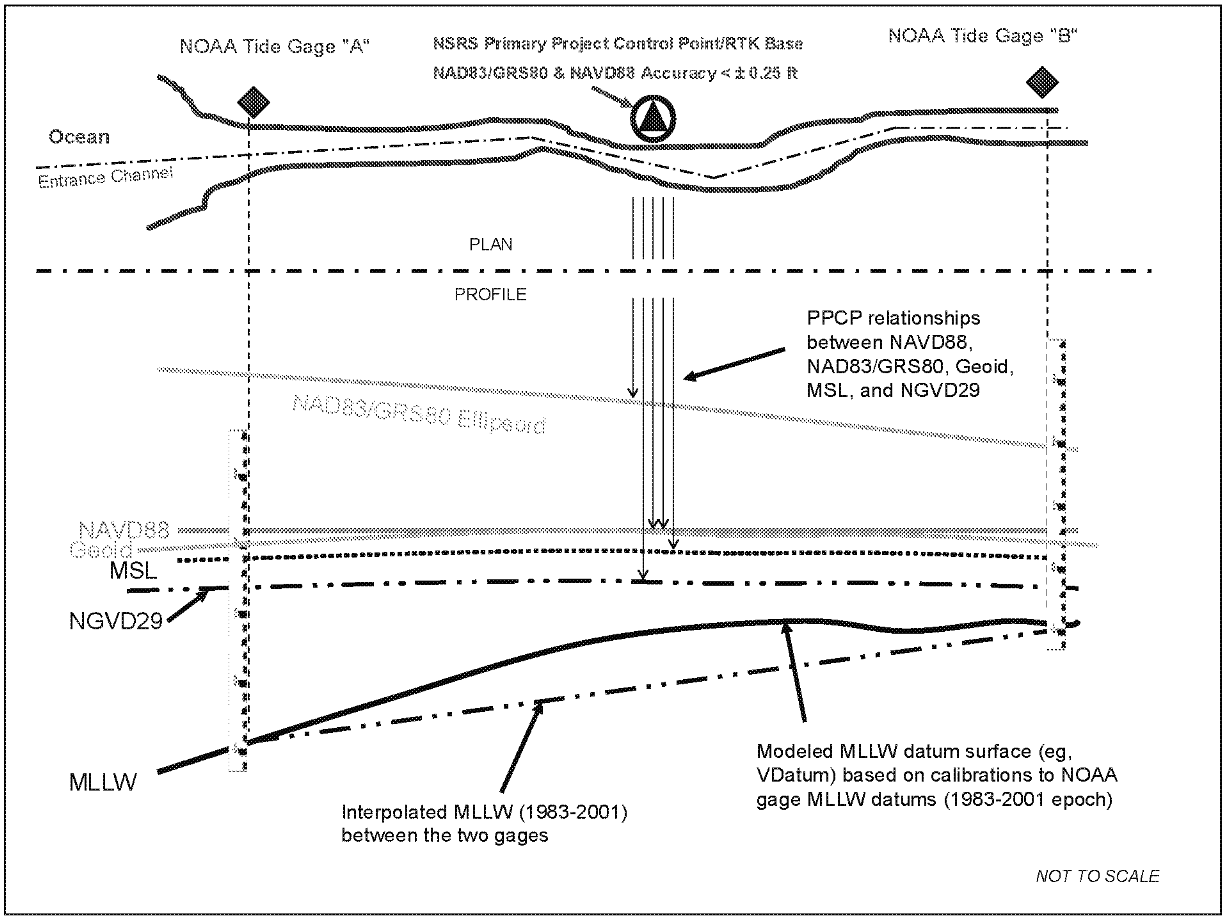


Figure 4-1. Geodetic and tidal datum relationships at a typical coastal entrance navigation project.

b. Tide gage and tidal bench mark references. Designate tide gages and tidal bench marks that reference the dredging datum for the project. These gage sites shall be used for calibrating RTN/RTK positioning systems to MLLW. Published MLLW elevation data for reference PBMs at these gages becomes the reference dredging datum for the project. Gages from any agency (e.g., NOAA, USACE, USGS, States, etc.) may be used; however, the MLLW reference datum must be current and referenced to the latest official NOAA National Tidal Datum Epoch NTDE). Depending on the size of the project and tidal characteristics, more than one gage may be required. The two gages shown in Figure 4-1 provide redundant RTK calibration points, at the entrance and upstream from the entrance. If only one gage at the entrance existed on this project (i.e., NOAA Tide gage "A") then the upstream gage "B" would have to be established in order to adequately model the reference MLLW surface. Further details on gage references are covered in Section 4-4.

c. Geoid model. Designate a geoid model for reducing observed RTK ellipsoid heights of the local water surface to the reference orthometric datum—NAVD88. As shown in Figure 4-1, the reference ellipsoid, geoid, and NAVD88 are not parallel and differ spatially over the project. The geoid (i.e., NGS "hybrid" Geoid XX) will match NAVD88 at some NSRS benchmarks but may deviate slightly away from those fixed points. GPS receivers and hydrographic survey systems provide software to model and compute in real time the relationship between the NAD83/GRS80 ellipsoid and the geoid, as necessary to compute NAVD88 elevations at any point on the project. Further details are covered in Section 4-7.

d. MLLW tidal model. Designate a MLLW tidal model that provides the relationship between NAVD88 and the MLLW datum at any point on the project. As shown on Figure 4-1, the MLLW tidal model may be based on a simple interpolation between the gages, or by a hydrodynamic tidal model, such as "National VDatum," that refines the actual MLLW variations due to topographic and bathymetric effects. As shown in the figure, the tidal model must also be related to the current NTDE. Further details on tidal models and VDatum are covered in subsequent sections in this chapter.

e. Tidal phase and water surface elevation corrections. Designate procedures used to correct for tidal phase and hydrodynamic/meteorological effects on the water surface elevation throughout the survey area relative to the location of the reference gage. This correction is not shown in Figure 4-1; however, the magnitude of this correction can far outweigh errors in tidal modeling. Details on the use of RTN/RTK methods to correct surface elevation measurements are covered in Section 4-7.

4-3. Establishing Primary Project Control Point (PPCP) References. This section provides guidance on establishing PPCPs needed to reference excavation grades on a navigation project.

a. Orthometric and tidal datum relationships. As outlined in Chapter 1, it is essential that the relationship between geodetic, tidal, and ellipsoidal datums be firmly established at a navigation project. This relationship is essential for determining the water surface elevation using RTK survey methods.

(1) Figure 4-2 illustrates the relationship between these datums at a PPCP and a tide gage. The tidal bench mark PBM A “000 9999 A” is used to reference the gage and contains only the elevation relationship between the gage zero and the various computed tidal datums. It does not have any geodetic datum elevation, which is common at many historical NOAA tide gage sites.

(2) In Figure 4-2, a nearby, published NSRS geodetic bench mark (PBM B “USED 123”) has established orthometric (NAVD88) and ellipsoidal heights, based on precise geodetic leveling and long-term static GPS observations to surrounding NSRS points. In cases where the NSRS mark has not been connected by precise geodetic leveling, the NAVD88 orthometric height may have been computed based on a GPS ellipsoid height observation coupled with the estimated geoid height, as was illustrated in Chapter 2.

(3) PPCP "USED 123" would likely be used as a reference base for RTK surveys of the project, and the tidal bench mark "000 9999 A" would be used to "site-calibrate" the RTK system to the reference dredging datum (e.g., MLLW and/or LWRP). The relationships between the datums at each PBM can be obtained by field leveling or GPS surveys connecting the two bench marks. This field survey effectively establishes the datum relationships at both PBMs.

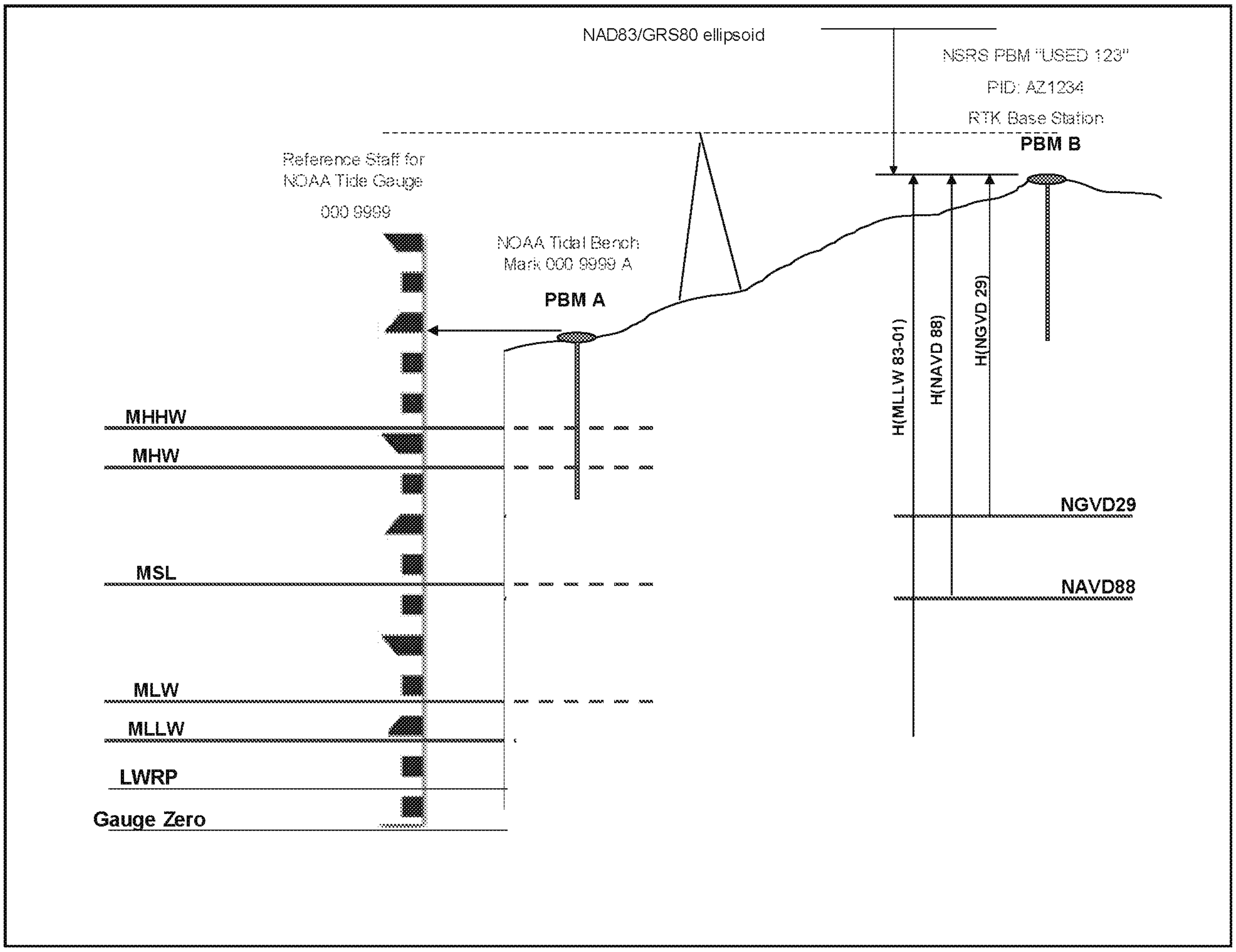


Figure 4.2. Establishing the relationships between orthometric datums and tidal datums at a gage site.

(4) If this gage in Figure 4-2 were located in a river transition area, a hydraulic Low Water Reference Plane (LWRP) stage, or a specified river datum such as the Columbia River Datum, is also defined at the gage site. Both tidal and non-tidal low water (or low flow) datums overlap at this site. See Chapter 6 for additional details on non-tidal river (low water) reference planes.

b. Establishing RTK base stations. RTK base stations on a PPCP can utilize either an existing NSRS PBM near the project site or a USACE PBM that is connected to the NSRS. In most CONUS coastal locations, CORS/OPUS observations are suitable and recommended for establishing a new PPCP or establishing an NAVD88 elevation on a published NSRS point with only horizontal control. Rarely would a long-term static GPS observation network be required to establish a new PPCP. The nominal PPCP accuracy standard of ± 0.25 ft (X-Y-Z) should be adequate for an RTK base, noting that the "Z" (MLLW) calibration is performed relative to a tidal PBM, not the PPCP elevation determined from a CORS/OPUS observation.

(1) RTK or RTN coverage in the project area must be assessed to determine the number of PPCPs needed to reach the project limits. In areas beyond reliable real-time data links, post-processed kinematic (PPK) procedures may be an option. In large open bays, and beyond reliable single-base RTK positioning limits, a PPK solution may be a necessity.

(2) In areas covered by government or commercial RTNs, an NSRS PBM is required near the project site to perform RTN site calibration.

(3) If static GPS network observations are needed to establish NSRS control on a PPCP or tidal PBM, then the procedures outlined in Chapter 3 should be followed. This may be necessary in isolated project areas or in OCONUS.

c. Connecting NOAA tide gage reference bench marks to the NSRS (NAVD88). It is desirable to reference MLLW datums at tidal bench marks to NAVD88. In order to support NOAA's program to update tidal bench mark elevations to NAVD88, tidal bench marks may be positioned using the CORS/OPUS methods described in Chapter 3. These GPS elevation observations will be input into the NSRS using the procedures described in Chapter 3. Recovery notes and updated descriptions on CO-OPS tidal bench marks not yet published in the NSRS (but published in the NWLON database without a NGS "PID" link) should be transmitted directly to CO-OPS.

(1) In some cases, NOAA tidal bench marks may be used as a PPCP for an RTK base if they are more suitable than the NSRS PPCP. In Figure 4-2, survey connections by differential leveling from the NSRS PBM "USED 123" to the tidal bench mark "000 9999 A" would provide adequate X-Y-Z control on the tidal bench mark to be used as the RTK base.

(2) If the NOAA tidal bench mark is distant from the nearest NSRS PPCP, then CORS/OPUS observations at the tidal bench mark are recommended; establishing < ± 0.25 ft horizontal and vertical accuracy on this point which is adequate for initializing RTK observations.

d. Summary. Figure 4-3 outlines the decision flow process involved in establishing and designating a PPCP used for RTK control on a navigation project.

4-4. Designating a Primary Tidal Reference Gage for a Navigation Project. All navigation projects must have one or more primary tidal bench marks that are directly referenced to an established tide gage. The gages must adequately model the project area and be suitable for RTK calibration purposes. A gage's computed reference datum (e.g., MLLW or LMSL) shall be based on relatively current observations and shall be referenced to the latest NTDE established by NOAA. The gage shall also have a sufficient number of tidal reference bench marks. The procedures for computing the reference MLLW datum at the gage shall be consistent with NOAA standards and specifications. This section describes the process for evaluating the adequacy of existing gage data at a project site, and if deemed inadequate, the steps needed to establish a new reference datum.

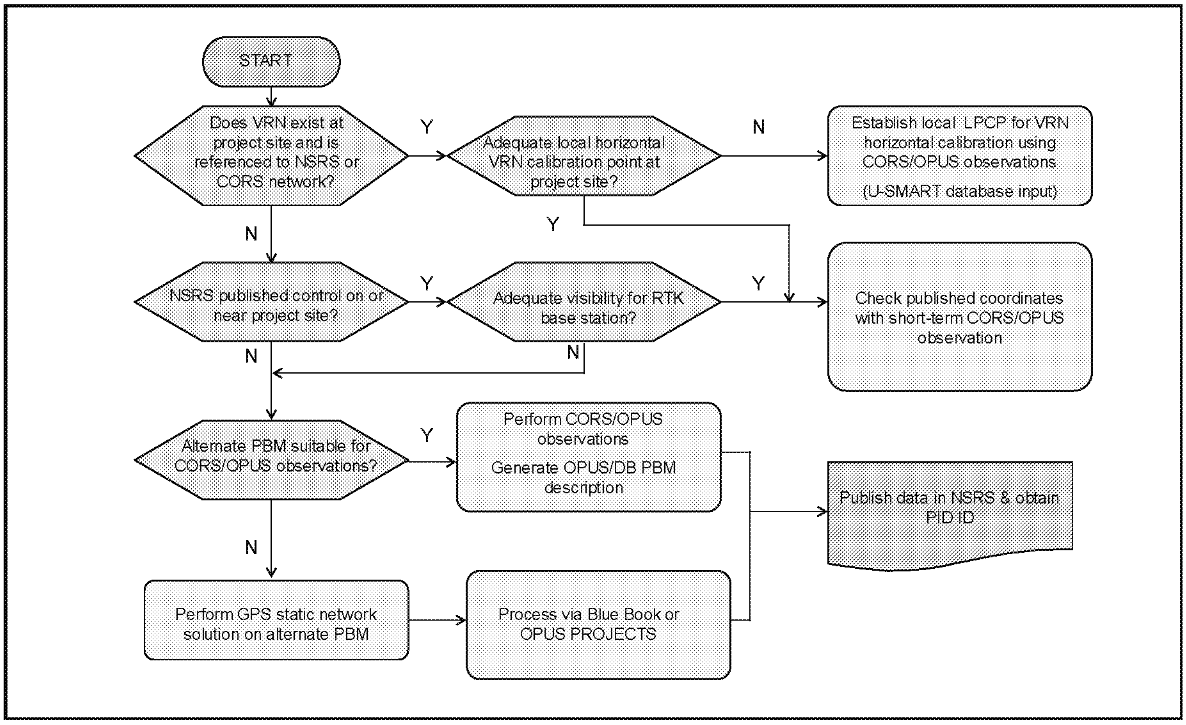


Figure 4-3. General decision process for establishing a navigation project PPCP.

a. Assessing the quality of existing tide gages and computed water level datums. The NWLON is the NOAA nation-wide network of permanently operating tide gages with accepted tidal datums and published bench mark elevations. It also includes the network of historical NOAA tide gage locations that have published tidal datum elevations relative to the latest NTDE. The navigation reference datum on a project site must be adequately connected with this NOAA NWLON network. This implies using either a NOAA gage site that is on, or is connected with, the NWLON, or a locally operated gage that conforms to NOAA/CO-OPS specifications. Isolated bench marks (those of USACE or any other agency) that purport MLLW or MSL reference elevations should be considered highly suspect unless their connection with a NWLON gage site can be firmly established. These connections are usually performed by simultaneous comparison methods, direct differential levels, or static GPS connections to a NOAA tidal bench mark. Any such marks must also contain an NTDE designation attached to their elevation that signifies it has been adjusted to the current NOAA tidal epoch.

(1) Use of active or historical NOAA gages. Published NOAA tidal bench marks are found on or near the vast majority of USACE deep-draft and many shallow-draft projects. These tidal PBMs may be referenced to an active NOAA gage or a historical NOAA gage with archived tidal data. Since few of USACE's 900+ navigation projects have actively operating NOAA gages, the adequacy of historic gage data must be evaluated. This would include assessing the period of record, the age of the data, subsequent channel deepening or realignment, inlet changes, jetty or breakwater modifications, etc. These physical changes may have modified the tidal characteristics since the gage data were recorded. For example, datums at a site computed from a 30-day series in 1970 may be suspect, particularly if subsequent construction or other physical changes have modified the tidal characteristics in the area. NOAA has dropped

published bench marks sheets from historical short-term stations that were established prior to the 1970's. In such cases, a new gaging program to update the reference datum may be warranted. Procedures for establishing tidal datums using short-term gage observations are described in "*Computational Techniques for Tidal Datums Handbook*" (NOAA 2003).

(2) Tidal bench mark recovery at historical NOAA gage sites. Tidal bench marks at historical NOAA gage sites are often lost or impossible to recover due to dated descriptions. Ideally, at least two tidal PBMs should be recovered to have confidence in the stability of these marks and their reference MLLW datum. Third-Order leveling procedures are considered adequate for this purpose. Additional tidal PBMs should be set such that a total of three to five reference marks are available at the gage site. One of the tidal bench marks should be designated as the primary "PPCP" tidal datum reference for the project and placed in the NSRS.

(a) If only one tidal PBM is recoverable, then the long-term stability of that PBM must be assessed if it is to be used as a primary reference. If no PBMs are recoverable, then a new gaging program would likely be warranted to reestablish the tidal datum—especially on deep-draft projects.

(b) Exceptions to the above may exist at less critical shallow-draft projects with reliable VDatum coverage. In such cases, the VDatum estimate of the NAVD88-MLLW difference may be used. The NOAA Coast Survey Development Laboratory (CSDL) "VDatum Team" should be consulted before making this determination.

(3) Use of other agency tide gages. Many other local, state, and Federal agencies including USACE operate tide gages that may be used to reference navigation datums. As with NOAA gages, the quality of the gage data (e.g., datum computation) and reference bench marks must be assessed. Often these gages are referenced to only one bench mark. The stability and quality of this single reference bench mark must be evaluated. If this gage is to be used as a project reference, then additional reference PBMs should be set with at least one PBM in the NSRS. In any case, for hydrographic survey tidal control, a current NTDE MLLW elevation must be established.

(a) Figure 4-4 illustrates NAVD88 orthometric connections to tide gages from other agencies that may be in the vicinity of the project area. Static GPS baselines are observed from published NSRS control points in the region to a local LPCP set near the gage site. Gage reference PBMs and staff zeros are leveled in from the LPCP. The gage datum relationship to NAVD88 is documented as shown in the figure. Additional gage reference PBMs are set in the vicinity of the gage.

(b) Figure 4-5 shows a case where the original gage reference point is updated and a new reference LPCP PBM is set. The primary reference PBM should be documented in the NSRS and additional gage reference PBMs established. Gage reference points must be clearly documented as shown in the figure.

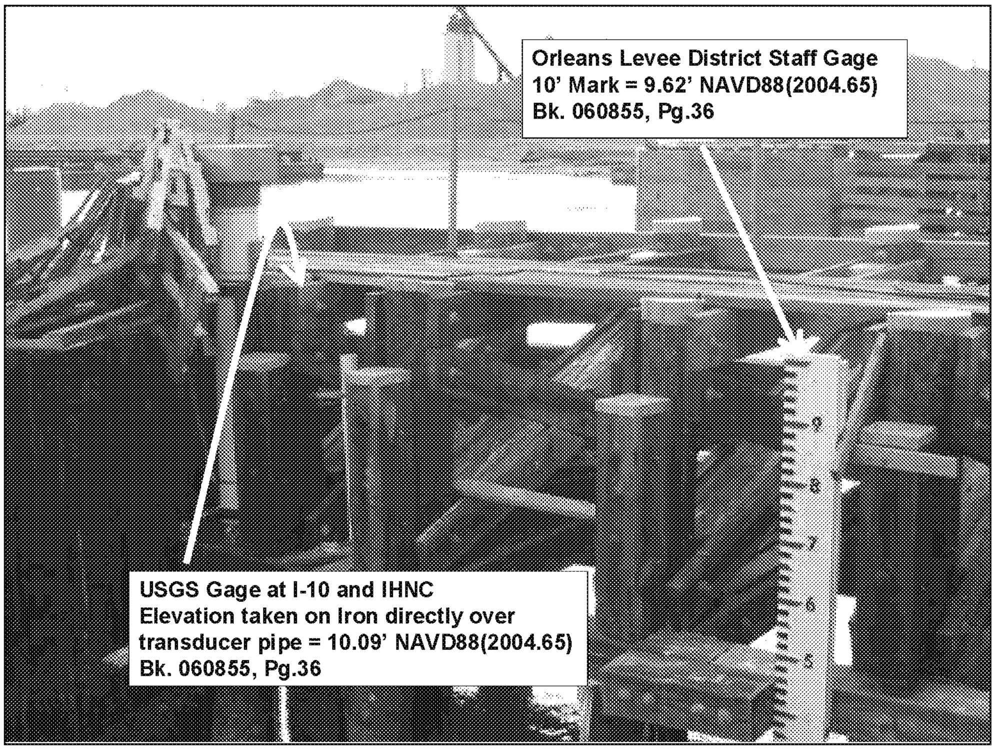


Figure 4-4. Gage reference elevations (USGS and Orleans Levee District gages at I-10 and Inner Harbor Navigation Canal (IHNC)—from IPET 2007).

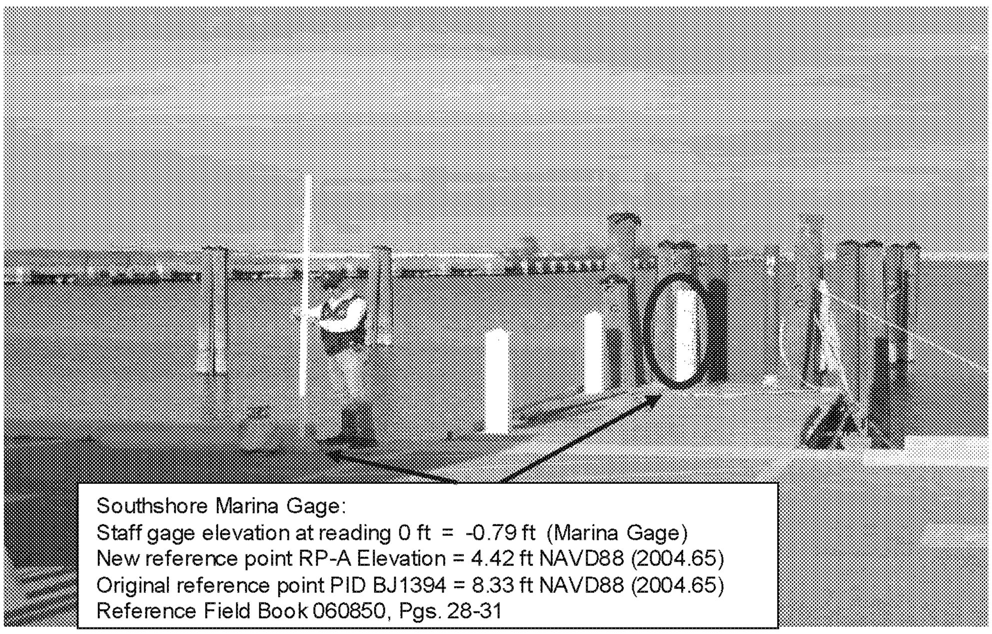


Figure 4-5. Revised gage reference points and elevations. The above photo shows location of PBM "RP-A" and red circle shows staff gage.
(Orleans Levee District gage at Southshore Marina, Lake Pontchartrain--from IPET 2007)

b. Projects with inadequate reference gages or undefined datums. Many USACE navigation projects, particularly isolated shallow-draft projects, do not have tidal datum references that can be reliably related to the current NOAA NWLON gage network. Typically, these projects have been referenced to a local datum or a legacy NGVD29 reference. These legacy reference datums may or may not be referenced to any tide gage. In other cases, the density of gages is inadequate to model the tidal regime over the project, or VDatum coverage may not extend to the head of the maintained navigation channel. This may occur on intracoastal waterways or on projects where the head of maintained navigation is distant from the coastal entrance. A number of options exist to bring these projects into compliance with ER 1110-2-8160, all of which are dependent on status and use of the project, commercial traffic, and related funding availability. These options may include:

(1) In coordination with NOAA CO-OPS, install a short-term tide gage to develop an updated reference datum using simultaneous comparison techniques relative to NOAA NWLON primary or secondary gages (see NOAA 2003). A 30-day observation period will suffice for most USACE navigation projects; however, 90-days are preferred by NOAA for QC purposes and to minimize datum errors. Longer gage observations (e.g., 3 to 12 months) may be required on more critical deep-draft projects. Less critical shallow draft projects may be effectively referenced to the NWLON with 7-day simultaneous gage observations where datum errors are not deemed critical to the project.

(2) If the project area is covered by a NOAA VDatum model, use this model to estimate the tidal datum relationship relative to NAVD88 on an established PPCP used for referencing RTN surveys. Check with NOAA CO-OPS as to the reliability of the VDatum model in the area. This would represent an interim solution for non-critical shallow draft projects with no maintenance funding. The NOAA VDatum model must be calibrated at existing or historic gage sites—see Appendix D. If no historic tide gage data exists for the project, then a gage may need to be established to calibrate the VDatum model.

(3) Maintain a legacy tidal datum reference noting the uncertainty of this reference on all published data for the project. VDatum may be used to estimate the datum relationships at the project site. This option may be applicable for inactive, soft-bottom, shallow draft projects that have not had any significant funding or maintenance activity in decades (i.e., funding a $50,000 to $100,000 tidal gaging and modeling program could not be economically justified).

c. Navigation project tide gage and modeling options. Figure 4-6 illustrates five of the more common cases of tide gage and tidal model coverage found on USACE navigation projects. The following sections outline possible corrective actions needed to bring the project into compliance with ER 1110-2-8160. Larger projects may require more than two gages to calibrate VDatum models for referencing hydrographic surveys and dredging operations—e.g., Tampa Harbor, Florida as illustrated in Appendix D.

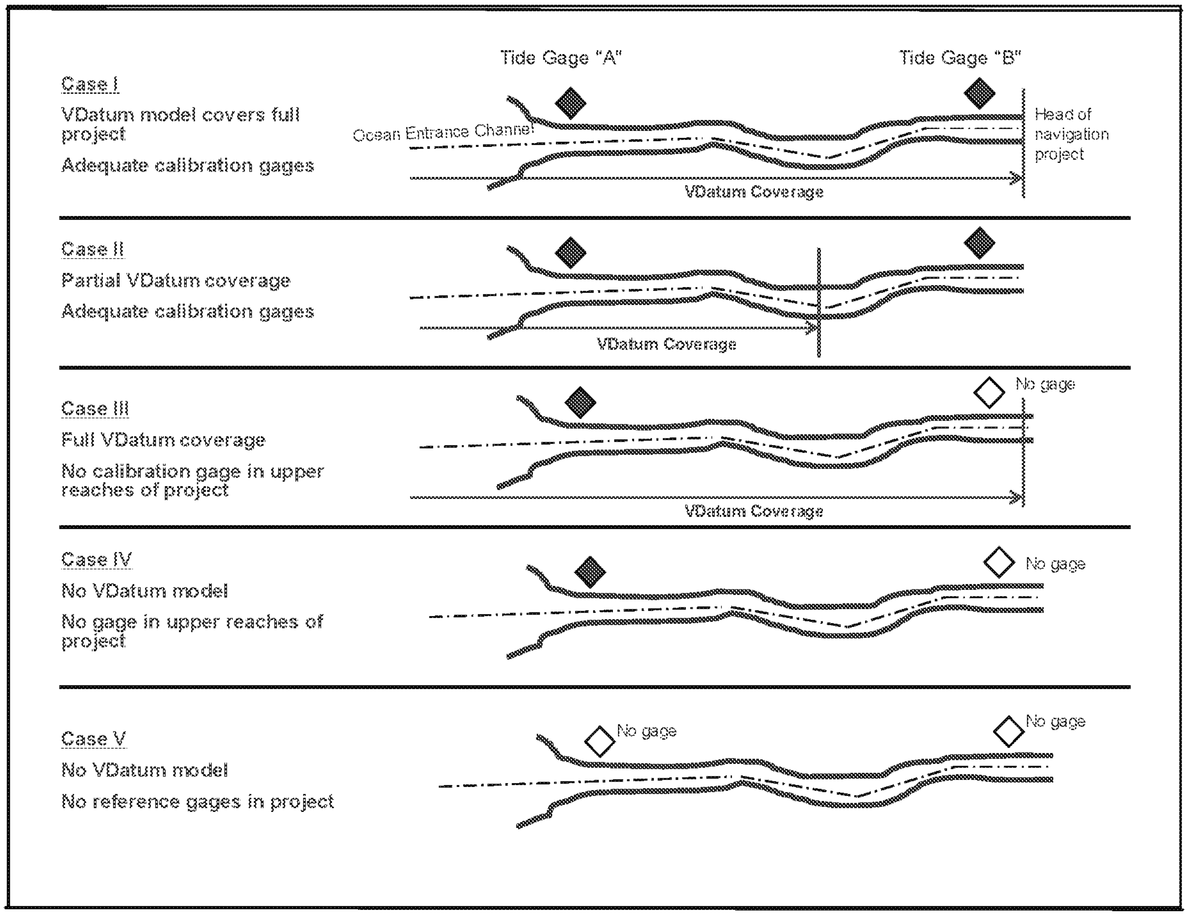


Figure 4-6. Tide gage and VDatum coverage cases that may exist at a navigation project. RTK/RTN surface elevation measurement is assumed. Tide gages are referenced to NOAA NWLON network.

(1) Case I. This case has adequate gage and MLLW datum model coverage to calibrate and reference RTK/RTN surveys over the entire project.

(2) Case II. Although existing tide gages are sufficient to reference the project, VDatum coverage does not extend over the entire project. In this case, the MLLW datum model would have to be interpolated between the VDatum model limit and the upstream gage.

(3) Case III. This case is an example of inadequate gage coverage to calibrate the VDatum model in the upstream reaches, and to reference surveys in these upper reaches. The VDatum model may adequately depict the MLLW reference surface throughout the project but reliance on one calibration gage at the entrance may be problematic if the distance upstream and tidal range variation is significant. For small, shallow draft projects, a single calibration/reference gage may be adequate. Likewise, small deep-draft projects only a mile or two inland from the entrance can be covered by a single gage. For projects of extended lengths upstream, an additional reference gage needs to be established. To correct this case, a short-term tidal comparison relative to the

entrance gage would be performed. This may entail establishing a temporary gage for a comparison period of 3, 7, or 30 days, depending on the tidal characteristics in the area.

(4) Case IV. This case is similar to Case III except there is no VDatum model covering the project. As in Case III, an upstream tide gage would need to be established to perform a datum comparison with the entrance gage. The MLLW reference plane between the two gages could be modeled by spatial interpolation methods. The offshore entrance channel datum relationship would have to be extrapolated from the entrance gage, unless other tidal data are available. More robust tidal modeling methods described in Section 4-6 would better model the river and offshore entrance channel.

(5) Case V. This is a "worst case" condition—no existing or historic gages at the project. Depending on various funding and maintenance levels, a full gaging program would be needed to model the project. Two short-term gages would be established for periods of 30 days or more, from which datum comparisons are made with nearby NOAA NWLON stations. The MLLW model would be developed using one of the methods described in Section 4-6.

d. NOAA requirements for short-term tide gages needed to update tidal models at a navigation project. When historical NOAA tide gage sites are occupied, or additional gaging data are needed to model the tidal regime at a navigation project, NOAA requires the following minimum standards in order for the site to be included in the CO-OPS database.

(1) Types of recording gage. At a new site, any NOAA approved type of temporary gage that can measure recorded water levels at 6-minute intervals is suitable. The gage must be firmly tied in and referenced to the local tidal bench marks at the site.

(2) Location of temporary gage. As needed to cover the navigation project and survey calibration. To be coordinated with NOAA CO-OPS.

(3) Length of record. Minimum of 30 days. Longer term if required by NOAA CO-OPS. A shorter term—3 to 7 days—may be used for adding gages within projects for use in calibrating hydrodynamic models and referencing RTK/RTN hydrographic surveys.

(4) Tidal bench marks. Five bench marks are required around the gage site. Follow mark construction requirements outlined in EM 1110-1-1002 (*Survey Markers and Monumentation*). No deep driven rods are required. Type C, F, and G marks are acceptable.

(5) Data format and submittal. Follow NOAA CO-OPS submittal requirements.

(6) Datum transfer computations. Follow NOAA CO-OPS simultaneous comparison standards—see NOAA 2003. NOAA CO-OPS will check datum transfer computations if they are performed in-house or by an A-E.

(7) Third-Order leveling between tidal bench marks. Follow standard procedures in EM 1110-1-1005 (*Control and Topographic Surveying*) for both new and existing gage sites.

(8) Primary tidal bench mark elevation. Tidal bench marks at both new and existing sites will be referenced to and input to the NSRS using CORS/OPUS input methods outlined in Chapter 3.

Detailed procedures for establishing tide gages and computing tidal datums at navigation projects can be found in Section 4 (*Tides and Water Level Requirements*) of "*NOS Hydrographic Surveys Specifications and Deliverables*" (NOAA 2009).

e. Referencing projects to the current tidal epoch. USACE projects must be referenced to the current NTDE defined by NOAA. NOAA periodically updates the tidal datums throughout CONUS and OCONUS to account for sea level change (rise or fall), local land settlement of tidal gage PBMs, and other factors. These periodic apparent sea level adjustments can be significant—ranging from 0.2 ft to 0.5 ft over the last 19-year update period (1983-2001) on the Atlantic East Coast. Projects not updated since the 1940s would have significantly larger differences—note the upward "apparent" sea level trend at Annapolis, MD shown in Figure 4-7. These adjustments represent systematic changes to the local reference datum (e.g., MSL or MLLW). They also represent systematic biases in navigation project depths or shore protection structure elevations.

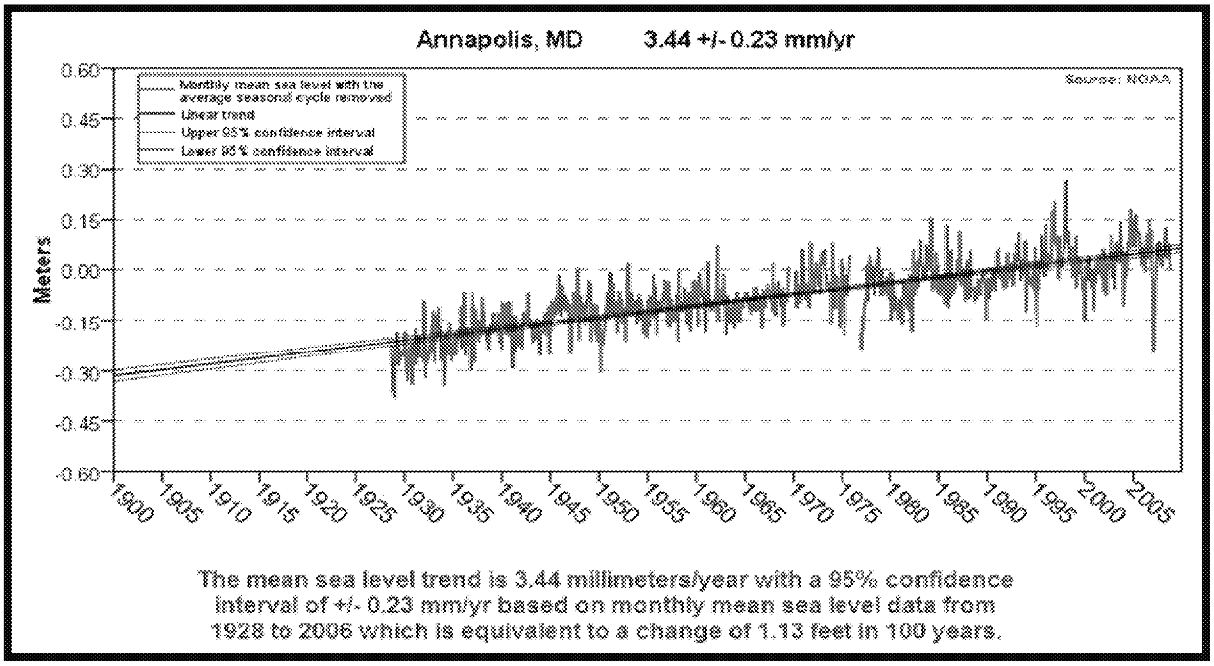


Figure 4-7. Sea level trends at Annapolis, Maryland.

(1) Sea level change impacts on tidal datums. Generally, on most CONUS East and Gulf Coast locations, sea level rise results in maintaining deeper navigation projects than were authorized, and overdredging if the sea level rise is not accounted for. Conversely, on shore protection structures, sea level rise results in less protection than originally designed, assuming this predicted rise was not factored into the design. Numerous USACE, NOAA, and academic technical publications provide guidance on estimating future sea level change for use in the

design of project grades. USACE technical guidance on assessing sea level change recommends that potential relative sea-level change must be considered in every USACE coastal activity as far inland as the extent of estimated tidal influence ... and that fluvial studies (such as flood studies) that include backwater profiling should also include potential relative sea-level change in the starting water surface elevation for such profiles, where appropriate. Sea level change projection uncertainties must be coupled with the uncertainties in the reference datum relating the projected sea level parameters. Refer to Chapter 9 for uncertainties associated with reference datums.

(2) Impact of tidal epoch changes on dredge clearance surveys. Figure 4-8 illustrates the impact of a tidal epoch change on a project that was dredged relative to the superseded 1960-1978 tidal epoch. Adjustment to the latest epoch (1983-2001) significantly reduced the number of strikes above grade that would have required additional dredging had the superseded epoch been held. Of importance is that the required dredging grade of 36.0 ft on the 1960-1978 epoch was 36.22 ft on the 1983-2001 epoch—the project was overdredged by 0.22 ft.

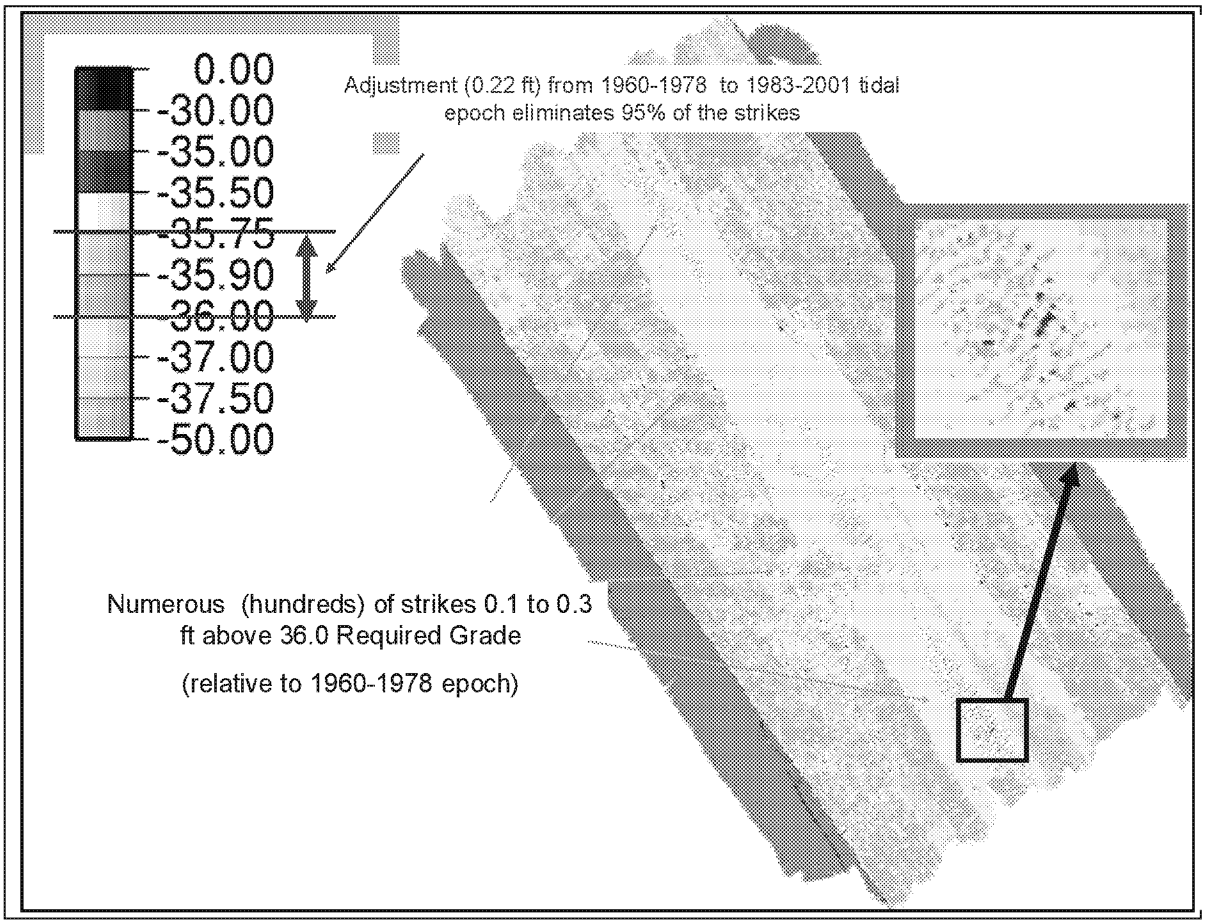


Figure 4-8. Impact of tidal epoch updates dredging strike detection and clearance grades.

(3) Epoch updates are averages from long-term estimates. The adjusted sea level or MLLW datum elevation is based at the midpoint of the epoch. Thus, the current epoch (1983-2001) is averaged about 1993. Tidal epoch adjustments are easily corrected by ensuring projects

are updated when NOAA completes a periodic epoch change. In areas with significant rates of sea level changes or subsidence, NOAA CO-OPS should be consulted to assess the need for shorter 5-year modified tidal datum epochs. NOAA has introduced modified 5-year tidal datum epoch procedures in areas of Louisiana and Texas (due to rapid subsidence) and Alaska (due to rapid land uplift).

4-5. Tidal Datum Uncertainty Estimates. Tidal datums used to reference USACE navigation projects contain two major error sources. These include (1) The regional accuracy of the MLLW datum computed at the project reference gage relative to 19-year NWLON stations, and (2) The local or relative spatial accuracy of the MLLW datum model relative to the project's reference tide gage and the reference orthometric datum (currently NAVD88). If RTN or RTK survey techniques are performed, then the uncertainties in the ellipsoid height measurement and geoid model must be factored into the overall "tidal-geoid" model covering the navigation project. If RTN or RTK surface elevation measurements are not used (i.e., tide readings from a gage are extrapolated to the project site without phase or range correction) then no readily defined accuracy estimate can be made, other than assuming that "worst case" tidal range, tidal phase, and hydrodynamic meteorological conditions occur between the gage and project site.

a. Estimates of NOAA tidal datum regional accuracies. Computed accuracies of tidal datums at a navigation project gage site refer to the uncertainties of the established reference datum at a gage site, such as MLLW or MSL. These estimates have application when a tide gage must be installed at a USACE project to reestablish the reference datum.

(1) Datum errors. The total error of computed tidal datums at a NOAA gage has the following component errors.

(a) Gage measurement error. The measurement error is a combination of the gage/sensor and processing error to refer the measurements to a station datum.

(b) Datum comparison error. The error in computation of equivalent 19-year tidal datums from short-term tide stations. The shorter the time series, the less accurate the datum, i.e., the larger the error. The closer the subordinate station is in geographic distance and in tidal difference to a control station, the more accurate the datum. Estimated maximum errors of an equivalent tidal datums based on one month of data is 0.26 ft for the Atlantic and Pacific coasts and 0.36 ft for the coast in the Gulf of Mexico (at the 95% confidence level).

(2) Tidal datum uncertainties at NOAA gages. Table 4-1 lists the estimated accuracy (i.e., uncertainty) of computed tidal datums for various lengths of gage observation periods. It indicates that, in general, tide stations with at least 3 months record have determined a tidal datum to within ± 0.15 ft. If a NOAA historical gage has some 12 months of record (which is common) then the accuracy of the computed MLLW datum at that point is better than ± 0.1 ft. Refer to NOAA 2001 (*Tidal Datums and Their Applications*) for more details.

Table 4-1. Generalized Estimated Uncertainties of Tidal Datums for East, Gulf and West Coasts when Determined from a Short Series of Record – at 95% Confidence levels.
(from Table 2, NOAA 2001)

Series length (months)	East Coast	Gulf Coast	West Coast
1	± 0.26 ft	± 0.36 ft	± 0.26 ft
3	± 0.20 ft	± 0.30 ft	± 0.22 ft
6	± 0.14 ft	± 0.24 ft	± 0.16 ft
12	± 0.10 ft	± 0.18 ft	± 0.12 ft

(3) Computed tidal datum error. The estimates in Table 4-1 are regional generalized uncertainties and should only be used for planning purposes. Instead of the regionalized approach in the above table, the following relationships may be used to estimate tidal datum uncertainties for each individual subordinate tide station. Specifically, the tidal datum uncertainty is determined from the relationship of the subordinate tide station to the control tide station to which the simultaneous comparison is being made. Assuming most subordinate tide stations for NOS hydrographic surveys are operated for less than one-year durations, the regression equations for mean low water for one-standard deviation ("*s*") estimates are of the form:

$$s_{1\ month} = 0.0068\ ADLWI + 0.0053\ SRGDIST + 0.0302\ MNR + 0.029$$

$$s_{3\ months} = 0.0043\ ADLWI + 0.0036\ SRGDIST + 0.0255\ MNR + 0.029$$

$$s_{6\ months} = 0.0019\ ADLWI + 0.0023\ SRGDIST + 0.207\ MNR + 0.030$$

$$s_{12\ months} = 0.0045\ SRSMN + 0.0128\ MNR + 0.025$$

where:

ADLWI is the absolute difference (in hours) in low water time intervals between subordinate and control stations.

SRGDIST is the square root of the geodetic distance between the control and subordinate stations, measured in nautical miles.

MNR is the mean range ratio that is computed from the absolute value of the difference in mean range of tide between control and subordinate tide stations divided by the mean range of tide at the control station.

SRSMN is the square root of the sum of the mean ranges computed by adding the mean ranges of the control and subordinate stations and then taking the square root of this sum.

For stations with series longer than one-year in length, the datum errors can be time-interpolated between the estimate at that station for a one-year series and the zero value at 19 years. Errors in tidal datums for accepted datums from 19-year control tide stations are zero by definition. Using these formulas, estimates of the datum error can be uniquely computed in the planning process for each subordinate tide station being used for the hydrographic survey using historical and accepted tidal datums on file.

(4) Recommended observation periods for USACE projects. When a gage is installed at a USACE project, the above NOAA accuracy estimates may be used to assess the required observation period. Based on Table 4-1, 30 days of simultaneous gage observations should usually be adequate to develop a reliable reference datum at the ± 0.25 ft level on most East Coast and West Coast projects. Deep-draft projects with critical keel clearance issues may warrant 3 to 12 months of observations. All gage installations, observation periods, and datum computations should be closely coordinated with, and approved by, NOAA CO-OPS.

b. Local or relative tidal datum accuracy. It is important to emphasize that the above uncertainties in the computed datum at a tide gage do not necessarily factor into the relative, or local, accuracy of an established tidal datum on a project. The computed/established reference datum at the gage is considered "fixed" for referencing dredging grades. Thus, for the purposes of defining dredging grades on navigation projects, errors in the "global" or regional determination of the reference datum are not usually an issue, other than providing regional uncertainty estimates of tidal datums for storm surge monitoring or like purposes. If a NOAA tidal PBM is used to reference grades at a project site, then both USACE channel clearance surveys and NOAA charts will be referenced to the same "local" MLLW datum.

(1) For small navigation projects with only one reference tide gage, the reference datum at the gage is the designated reference for the entire project, and RTK calibrations are performed to tidal PBMs at this gage. For larger projects with two or more tide gages, calibration discrepancies between the gages may result due to the absolute (regional) datum uncertainties between the tide gages. These calibration differences may or may not be significant. If significant, then a zoned calibration reference should be designated for each project reach—e.g., specify the tide gage to be used for specific channel reaches. The following Table 4-2 is an example of a zoned gage reference on a large 67-mile length project with VDatum coverage. In this example, VDatum model calibrations were made using a regional RTN network, resulting in 0.1 to 0.2 ft variations at the calibration gages. Construction survey plans in a given channel reach are fixed ("zoned") to the gages in the table—i.e., all users must calibrate RTN systems to MLLW at these specific gages for a given channel reach.

Table 4-2. Zoned Reference Gages for Tampa Harbor Channel Reaches.

Tampa Harbor Channel Reach	NOAA Gage	Station ID
Egmont Cuts Mullet Key Cut	Egmont Key Mullet Key	872 6347 or 872 6364
Cut A, Cut B, and Cut C	Port Manatee	872 6384
Cut D, Cut E, and Cut F	St. Petersburg	872 6520
Gadsden Point Cut to PI Cut A & C (HB) and Cut G (PT)	Gadsden Point	872 6573
Cut C (HB) and Alafia River Channel	Long Shoal-MacDill AFB	872 6604
Davis Island, Seddon Island Port Sutton, & McKay Bay Channels	Ballast Point Hooker Point Davis Island	872 6639 or 872 6668 or 872 6657
Cut J (PT) & Cut K (PT)	Port Tampa	872 6607

(2) Regardless of the absolute accuracy of a tidal datum for a project, the relative accuracy (i.e., "repeatability") is most critical for survey and dredging operations. In general, a local tidal datum relative accuracy of ± 0.1 ft should be achievable at most navigation projects where an established tide gage exists. RTN calibrations are performed at this gage and a VDatum type model is used to correct for local MLLW variations.

c. Dredging measurement & payment survey repeatability. As stated above, for USACE tidal datum modeling purposes, and subsequent maintenance dredging and construction of projects, the accuracy of a NOAA gage datum, (or acceptable datums from another agency's long-term gages) will be assumed as absolute—i.e., they will be assumed to have “zero error” ("zero uncertainty") irrespective of the actual computed datum uncertainties at a particular gage. This assumption is valid in that the final developed MLLW tidal model for the project (e.g., NAVD88-MLLW differences in VDatum) will also be considered fixed for project construction purposes. This fixed local VDatum model, when used with RTK, provides repeatability between users (surveyors, dredges, etc.), limited mainly by the precision of the RTK solution and the site calibration. This repeatability is critical for equitable dredge payment surveys. If RTK is not used, and zoning estimates relative to a water level gage are used, then repeatability will be dependent on tidal range and phase variations.

d. Tidal datum accuracies for navigation projects. Table 4-3 represents the desired accuracy of a navigation project model, considering the total propagated uncertainties (TPU) in both the MLLW datum and the geoid.

Table 4-3. Recommended Accuracies for Tidal Reference Datums on Navigation Projects with VDatum Coverage.

	Accuracy (95%)	Relative to Datum
Absolute accuracy of tidal datum relationship at gage	± 0.25 ft	MLLW Regional NWLON
Relative accuracy of local tidal model	± 0.2 ft	Local MLLW at PPCP Gage

Tidal-geoid model numerical resolution:	nearest 0.01 ft
Model 1D or 2D density in navigation channel:	100 to 500 ft (varies with tidal range)
Geoid model:	use latest available at time of study (currently Geoid 09)
Tidal-geoid model format:	1D or 2D (1D for linear navigation channels)

NOTE: The above standards are believed representative for most CONUS navigation projects. Exceptions may exist in extreme tide ranges or in parts of Alaska. See VDatum uncertainty models on NOAA VDatum web site.

In general, a full tidal-geoid model absolute accuracy of < ± 0.25 ft should be achievable at most deep-draft navigation projects where NOAA calibration gage data exists. Local (relative) model accuracy should be better than ± 0.1 ft on such a project—i.e., that accuracy relative to one or more local NOAA gages where VDatum coverage exists. Regardless of the resultant absolute accuracy of a tidal model for a region, the relative ("repeatable") accuracy is most critical.

4-6. Tidal Modeling Methods to Define Local MLLW Datums on Coastal Projects. Defining the MLLW datum tidal model on a navigation project requires the following basic actions: (1) ensure tidal datum reference planes (MLLW) are defined relative to published NOAA gages and tidal benchmarks, (2) ensure the latest tidal epoch adjusted by NOAA is used, (3) model the MLLW reference plane and geoid throughout the geographic extent of the project, (4) verify/calibrate the MLLW model at gage sites, (5) publish/disseminate the tidal-geoid model for users—e.g., a Kinematic Tidal Datum (KTD) file, (6) determine the NAVD88-MLLW datum relationship at tidal benchmarks, and (7) submit any field GPS or gage data to NOAA for their use in expanding the nationwide VDatum. Actions (1) and (2) are easily achieved as long as an existing or historical gage exists at the navigation project. This will likely be the case for the majority of the Corps' deep-draft navigation projects. If not, then a short-term gaging program will have to be developed in order to establish a tidal datum at a project. Any such effort must be coordinated with NOAA in order to ensure the project becomes included in the NOAA CO-OPS gage inventory. Project modeling—actions (3) through (7)—will require close coordination with District H&H elements, ERDC/CHL, and/or NOAA. In small tide ranges, or in survey areas that are small geographically and hydrodynamically simple, linear interpolation of the MLLW model will often be sufficiently accurate and economically developed. By 2012, VDatum models may already have been developed for most projects.

a. Modeling techniques. A number of techniques can be employed to model the variations in tidal datums on a coastal navigation project. These models reflect the changes in mean or diurnal tide ranges that occur on the project. They are configured to relate the difference between NAVD88 and MLLW spatially over the project since RTK observations of ellipsoid heights are reduced to a NAVD88 elevation of the local water surface. These models may be simple or complex depending on the project use and maintenance activity—ranging from assumed constant NAVD88-MLLW differences throughout the project to a full hydrodynamic tidal model of varying NAVD88-MLLW differences based on multiple gages in the project area. These various modeling options include:

(1) Constant NAVD88-MLLW model. Assumes no significant tidal range or phase differences occur between the reference gage and project site—i.e., a "tide correction" at a reference gage is extrapolated to the project site. This "model" is only applicable when the gage is close to a confined project site with a small tide range—i.e., minimal potential phase and wind effects between the gage and the site. The water level elevation ("tide correction") and the NAVD88-MLLW difference at the gage are assumed the same throughout the project. If RTK positioning is used under such conditions, variations in geoid heights must still be applied.

(2) Spatial interpolation model between tide gages. A simple linear or TIN spatial interpolation of the variations NAVD88-MLLW differences between tide gages. Examples of spatial interpolation modeling methods are shown in Appendix E.

(3) NOAA tidal zoning estimates. Tidal zoning models are estimates of tidal ranges and tidal phases at an offshore project site. Tidal zoning is used extensively by NOAA but only on isolated USACE projects (e.g., Chesapeake Bay). A further discussion on tidal zoning is at Appendix E.

(4) NOAA Tidal Constituent And Residual Interpolation (TCARI) model—a NOAA/CO-OPS spatially interpolated model. Incorporated in, and being replaced by, NOAA VDatum models.

(5) Hydrodynamically generated tidal models. Hydrodynamically generated tidal models that spatially develop the tidal regime and MLLW datum variations over the project.

b. Tidal datum models. Figure 4-9 illustrates a tidal datum model for a coastal inlet navigation project. As shown on the figure, the existing MLLW datum model is based on a straight-line interpolation between the gages. A hydrodynamic tidal model, such as VDatum, would fit (calibrate) the induced astronomical tide to the MLLW datums at each gage, as shown by the curved MLLW profile in the figure.

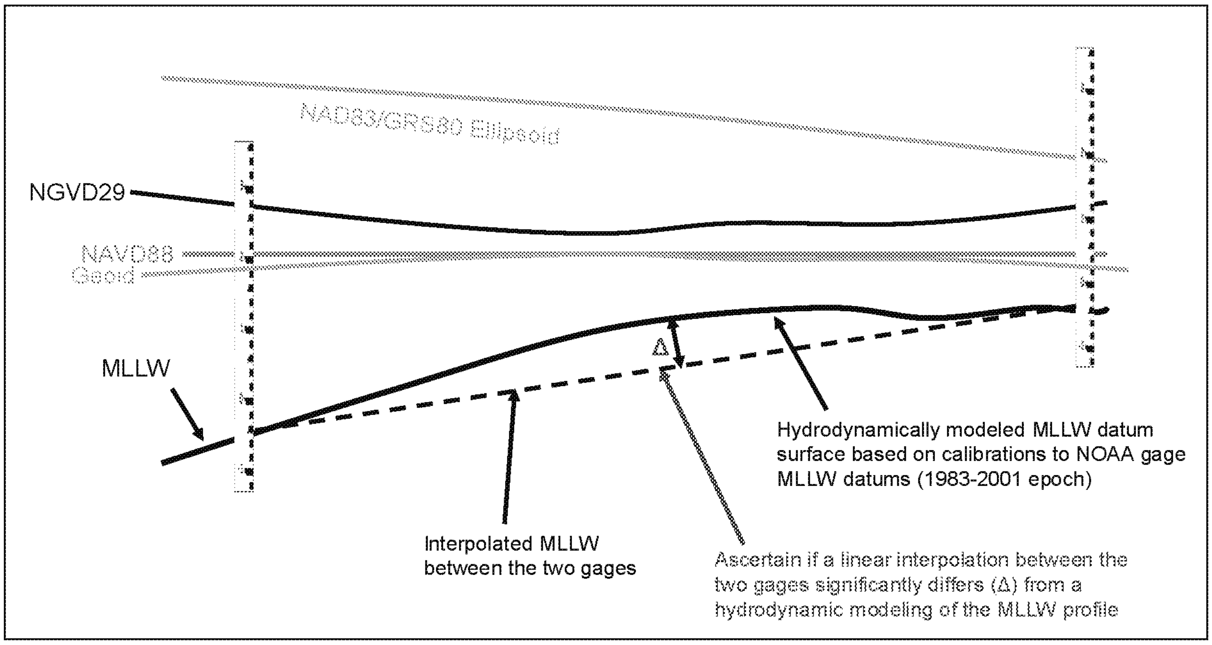


Figure 4-9. Modeled versus interpolated MLLW datums.

(1) Interpolated tidal models. Of significance is whether this project can be just as effectively modeled using a simple straight-line interpolation between the gages as opposed to running a full hydrodynamic model. In lower tide ranges, or with dense gage data, this would be the case. In general, if the estimated variation between a model and straight-line interpolation does not exceed 0.1 ft, then the straight-line interpolation would be acceptable. This variation is indicated by "Δ" in Figure 4-9. The use of validated VDatum models is recommended in lieu of linear interpolation.

(2) Geodetic reference datums. Figure 4-9 also depicts the relationship between other geodetic reference datums. The local geoid model would provide the undulation shown relative to NAVD88, and indirectly relative to MLLW. NOAA's VDatum model includes the transformations between all these datums.

c. Example of a spatially interpolated project. Appendix F contains an example of a Jacksonville District project (Canaveral Harbor) where spatial interpolations of the MLLW reference datum were estimated from NOAA gage data; both in the offshore Entrance Channel and in a semi-controlled pool. These estimates were made prior to receipt of VDatum model data which will supersede these estimates.

4-7. National Vertical Datum Transformation Software (VDatum). VDatum is a vertical datum transformation software tool developed by NOAA for coastal areas that allows users to transform geospatial data among a variety of geoidal, ellipsoidal, and tidal vertical datums. VDatum is important to coastal applications that rely on vertical accuracy in bathymetric, topographic, and coastline data sets, many of which may be produced on different reference datums but need to be merged for hydrodynamic surge models. VDatum has application to most, if not all, USACE coastal navigation projects. It also represents a defined datum reference for USACE projects.

a. Transformation datums. Currently the VDatum software is designed to convert between over 30 geodetic datums, including full continuous models of NAVD88 and MLLW, which are especially applicable to most USACE navigation projects. Various geoid models are also included. Figure 4-10 depicts the variety of datum transforms currently available in VDatum. Only the NAD83/NSRS2007 ellipsoidal datum is utilized on CONUS projects.

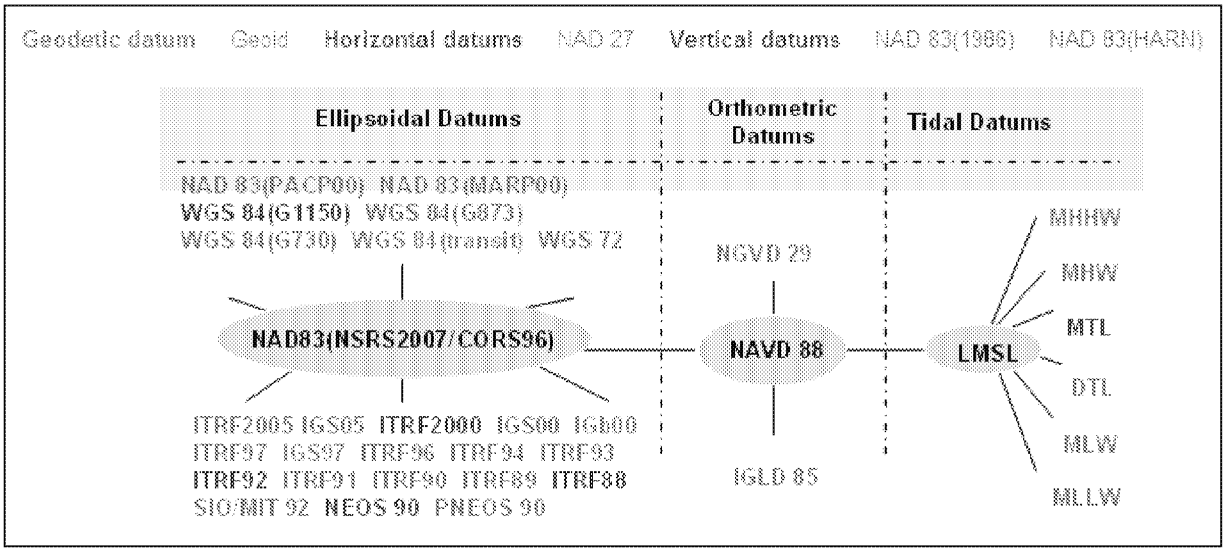


Figure 4-10. Primary VDatum transforms between ellipsoidal, orthometric, and tidal datums.

b. VDatum coverage. Figure 4-11 shows VDatum coverage as of 2010. It is anticipated that complete CONUS coverage will be available in or after 2012. Coverage of some OCONUS areas is in progress. In many cases, VDatum coverage extends up to the head of navigation on deep-draft harbors and ports.

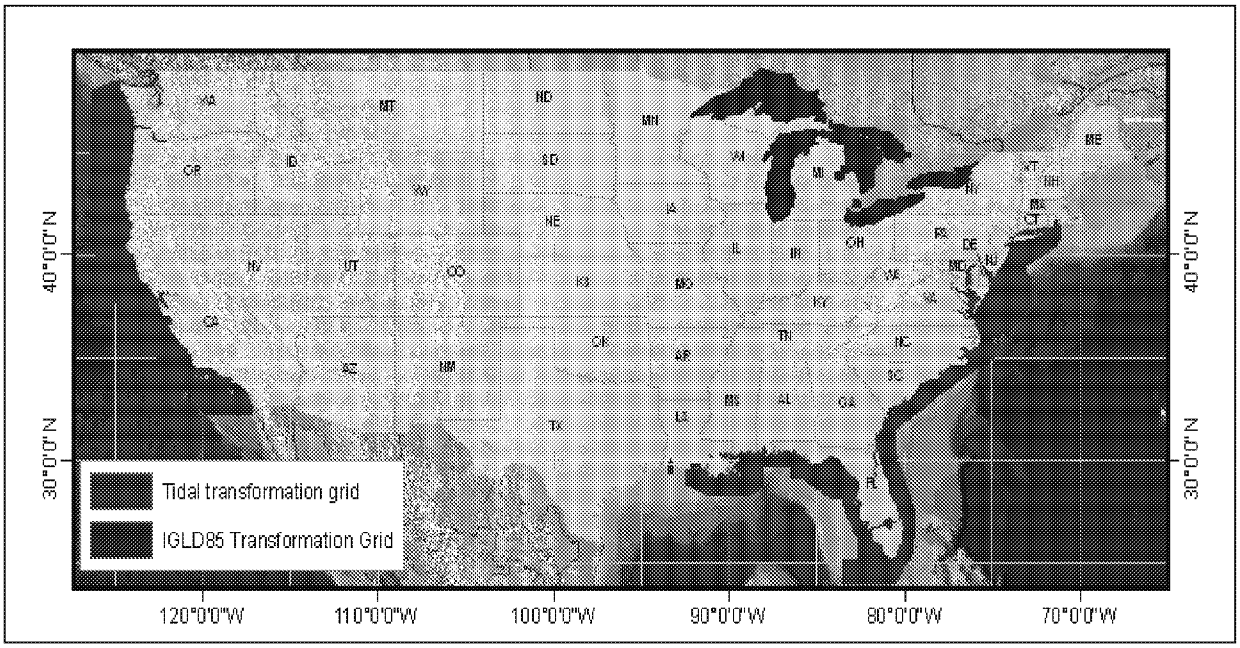


Figure 4-11. VDatum coverage in CONUS as of April 2010 (NOAA).

c. Use of VDatum for surveying and dredging applications. Most USACE applications will involve incorporating VDatum transforms with observed real-time GNSS satellite observations to obtain the elevation of the water surface relative to the local construction datum (e.g., MLLW, LMSL, IGLD85, etc). This water surface elevation, often resolved as a "tide correction" in RTN/RTK hydrographic positioning and orientation systems, is then applied to a measured depth to obtain a "corrected depth." The applicable VDatum ellipsoid-NAVD88-construction datum transforms in a project area are normally output to a 2D TIN model of the project area. This TIN model can then be input into surveying and dredging positioning/orientation software for real-time datum conversions at any point on the project. An example of this is the HYPACK "KTD" file. Future developments in survey and dredge positioning/orientation software will include a seamless input of VDatum transform models.

d. Site calibration. VDatum models of navigation projects need to be "site calibrated" (i.e., verified) prior to use in dredging measurement & payment or clearance surveys. This entails comparing observed water surface elevations at a reference NOAA tide gage/staff to those reduced through VDatum on a RTN/RTK survey positioning/orientation system on the vessel. Given the resolution of tide staff readings and RTK accuracy, tolerances approaching ± 0.2 ft would be expected. Uncertainty estimates for the various VDatum transformations are provided on NOAA's VDatum web site. An example of a VDatum site calibration is shown in Appendix D.

e. Further information on VDatum. Additional technical details on VDatum applications are available from the NOAA Coast Survey Development Laboratory "VDatum Team" web site and from "*Review of Progress on VDatum, a Vertical Datum Transformation Tool*" (Myers 2005).

4-8. Tidal Phase and Water Surface Elevation Variations over a Navigation Project. The major correction in the depth measurement survey of a navigation project is for tidal phase (latency) variations between the reference tide gage and the location of the dredge or survey vessel at the project site. Local hydrodynamic and meteorological effects (e.g., wind set up) changes the water surface elevation profile in the project. These variations due to tidal phase, along with other hydrodynamic or meteorological effects, increase with the distance from the tide gage. These systematic differences can exceed 1 to 2 ft in moderate range projects, and higher on projects with large tide ranges (over 10 ft) or experiencing adverse weather conditions. They are most pronounced during periods of full ebb and flood tide. Many dredging measurement & payment survey disputes and claims arise over lack of adequate compensation/correction for tidal phase and meteorological set up throughout a project site—see EM 1110-2-1003 (*Hydrographic Surveying*) for details..

a. Tidal phase latency variations. EM 1110-2-1003 and EM 1110-2-1100, (*Coastal Engineering Manual*), Part II-6, "*Hydrodynamics of Tidal Inlets*" have numerous examples of the tidal phase and MLLW range variations that typically occur between the ocean and bay at a typical coastal inlet. These tide curves do not include any hydrodynamic or meteorological effects which could, at times, exceed the basic phase variations. Modeling and correcting these tidal phase variations throughout the project is critical.

b. Water surface elevation measurements using RTK techniques. Tidal phase errors and weather/sea surface set up are effectively eliminated by using RTK surface elevation measurement techniques, coupled with inertial measurement and orientation systems. Local water level variations can be measured in real-time using these RTK techniques, either from a local RTK base station set at a PPCP or from a regional RTN system. RTK methods effectively measure the local water surface elevation relative to the ellipsoid; thus, providing direct corrections relative to a MLLW datum at a modeled offshore construction site.

(1) Dredging measurement & payment surveys performed using RTK methods will usually employ a combined tidal-geoid model from which to correct observed ellipsoid heights measured relative to the water surface; to obtain a surface elevation relative to the tidal MLLW model at the project site. Thus, the measured ellipsoidal height of the water surface at any point is corrected for (1) geoid model undulations, and (2) tidal range variations based on hydrodynamic models of the tide in the region. The RTK measurement process is illustrated in Figure 4-12. The actual offshore water surface level above local MLLW (i.e., a "tide correction") is thereby measured at every observation (typically 1 to 10 Hz) made by a survey vessel, dredge, or commercial vessel employing RTK methods; and an average surface level above local MLLW computed using filters and/or an inertial measurement unit (IMU) over a 30 to 120+ second filter period. As long as every user (vessel) employs the same tidal-geoid model for the region, then full repeatability of surface elevation measurements will be achieved. The relative accuracy of the RTK measured surface elevation and tide level will fall around ± 0.05 ft level. The tidal-geoid model developed for the project is considered as absolute.

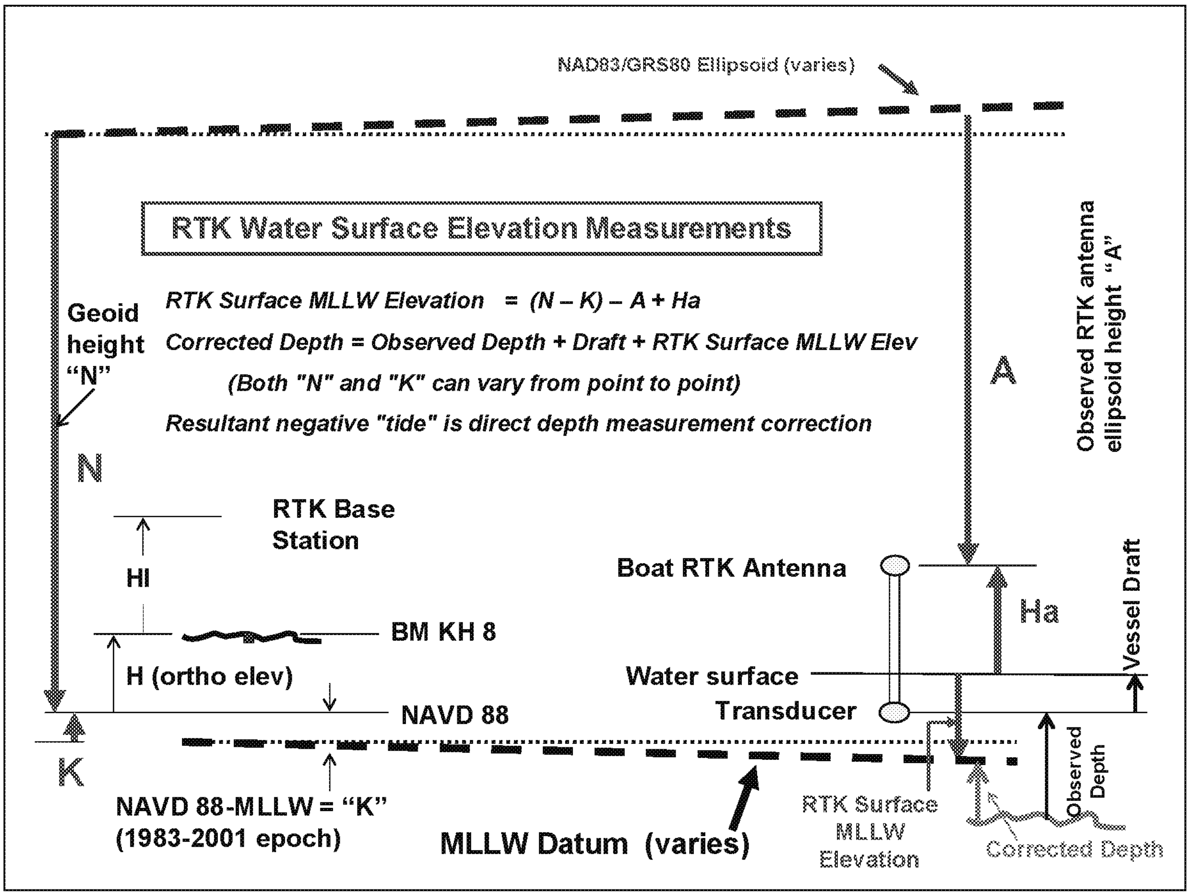


Figure 4-12. RTK Ellipsoid-Tidal-Geoid parameters for water surface elevation measurements. (Note: coordinate system is positive up)

Using the parameters shown in Figure 4-12, the following is an example of RTK observations and vessel depth measurements that derive a "corrected depth" on the MLLW reference datum. Note that observed depths and drafts are shown as positive values in Figure 4-12. Observed depths and corrected depths are shown as positive downward values.

RTK Parameters	Vessel Observations
N = (-) 71.29 ft	Observed Depth: + 40.0 ft
K = + 1.76 ft	Vessel Draft: + 3.0 ft
A = (-) 45.00 ft	
H_a = + 22.05 ft	

RTK Surface MLLW Elevation = (- 71.9 - 1.76) – (- 45.0) + 22.05 = (-) 6.0 ft

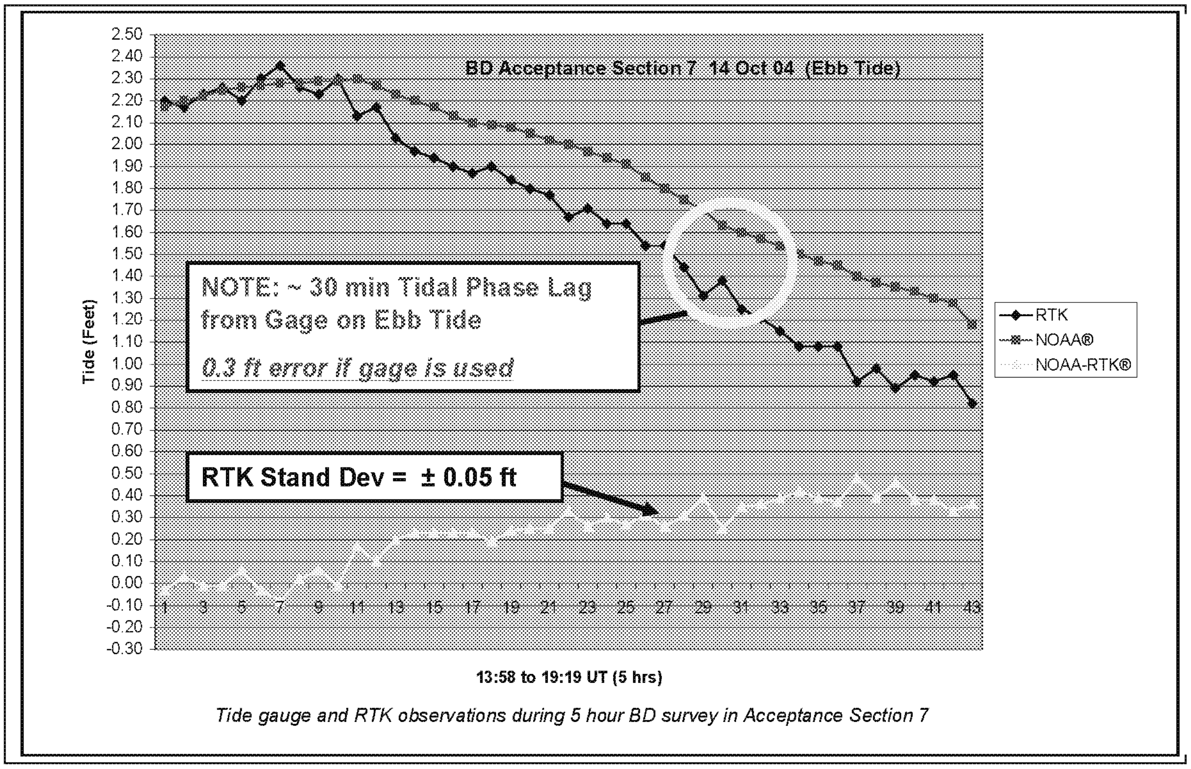
Corrected Depth = = + 40.0 + 3.0 + (- 6.0) = 37.0 ft

(2) Geoid model accuracy is a function of the location and density of NSRS vertical control and gravity data in the area. The predicted geoid undulation from the latest geoid model will be

used for offshore entrance channels—areas that obviously have no vertical control but have geoid height estimates using other techniques (airborne gravity). NGS should be contacted to confirm the accuracy of the predicted geoid model does not exceed reasonable tolerances. Likewise, the predicted tidal range in offshore entrance channels 3 to 10 miles seaward may have to be based on established regional models of the ocean tides. In such cases, the estimated accuracy of these regional models may be verified by contacting ERDC/CHL or NOAA. Alternatively, these offshore tidal ranges, and indirectly the geoid model, can be easily confirmed by observing long-term RTK data recorded during the course of a survey in the area.

(3) It is emphasized that the tidal-geoid model developed for each project must be published and disseminated to all users. This may be a simple ASCII file in the form of a gridded difference between NAVD88 and MLLW (NAVD88-MLLW), such as a "KTD" file used by commercial navigation dredging software (HYPACK®). Since most USACE navigation projects are linear, only a 1D model may be required—e.g., a tidal-geoid correction every 100-ft station down the channel centerline. This is adequate to cover the areal extent of a 100 ft to 1,000 ft wide channel. This file may periodically be updated if the MLLW tidal model for the region is significantly modified by NOAA. Thus, the file must clearly identify (metadata) the source of the data. Care must be taken in that in some navigation/dredging processors, the geoid correction may be performed separately by the GPS receiver from the MLLW tidal model correction—i.e., two distinct corrections. Thus the KTD file may contain only the tidal datum correction (NAVD88-MLLW or "K" in Figure 4-11) or may combine both the tidal datum correction "K" and the geoid correction "N." Users must also be advised that RTK, like any measurement system, must be periodically checked (and site calibrated/localized if necessary) against a physical recording tide gage or staff gage.

c. RTK versus gage surface elevation measurement. Figure 4-13 illustrates the application of using GPS/RTK elevation measurement for removing tidal phase and wind-induced errors on a Jacksonville District dredging project at Key West, FL. In this example, a constant 0.3 ft phase bias (and perhaps some wind setup bias) is generated during ebb tide at a point only 3 miles distant from the gage. This phase bias is significant given the tide range at this project is only about 2 ft. Had the NOAA tide gage been used to correct depth measurements during this survey, a 0.3 ft bias would have been translated to the quantity measurements in this Acceptance Section. As shown in Figure 4-13, the RTK-determined elevation of the sea surface at the dredging site was estimated to be accurate to ± 0.05 ft, effectively minimizing the tidal phase and potential meteorologically induced errors at this offshore project site. RTK operations are only successful if the MLLW to ellipsoidal difference are correctly modeled and understood prior to the survey as these two reference planes have slopes relative to each other.



Tide gauge and RTK observations during 5 hour BD survey in Acceptance Section 7

Figure 4-13. Offshore RTK tide comparisons with an onshore NOAA tide gage.
(Key West Harbor, FL Acceptance Section 7—3 miles south of Key West in open water)

d. RTK survey procedure references. See EM 1110-2-1003 for additional details on the impacts of tidal phase errors on dredging measurement & payment surveys. Refer to EM 1110-1-1003 (*NAVSTAR GPS Surveying*), EM 1110-1-1005, and hydrographic survey system user manuals for detailed RTK survey procedures.

4-9. Channel Control Framework Drawing Notes for Navigation Projects. Detailed datum metadata are required on drawing notes for plans and specifications surveys, channel condition surveys, and measurement & payment surveys. It is especially critical that bid documents for dredging projects contain the essential horizontal and vertical datum parameters, gages, and transformation models that will be used during construction. See Appendix D for an example of drawing notes used on a Jacksonville District project with VDatum and partial RTN coverage.

4-10. Summary of Evaluation Factors for Determining a Reference Tidal Datum on a Navigation Project. Table 4-4 outlines a general decision flow process for determining the reference tidal datum for a navigation project, based on the issues discussed above.

Table 4-4. Tidal Reference Evaluation Factors.

I. Existing Tide Gage Data

Does project have an existing tide gage that is adequate to define the tidal datum?
If NO, go to IV.

Is gage data based on relatively recent observations? If NO, go to IV.

Is gage observation series length adequate based on project use? If NO, go to IV.

Is gage datum based on or can be updated to current tidal epoch? If NO, go to IV.

Have physical modifications to project possibly impacted historical gage datum data?
If YES, go to IV.

Does gage location and density adequately model the entire project? If NO, go to III.

II. Reference Tidal Bench Marks

Were two or more tidal bench marks recovered at existing gage station?
Only one tidal bench mark recovered: Evaluate stability & reliability
No tidal bench marks recovered? If YES, go to IV.

Are tidal bench marks stable based on field level checks? If NO, perform checks.

Does existing gage site contain 3 or more reference PBMs? If NO, add PBMs as required.

Do any tidal reference bench marks need to be published in the NSRS?

III. Tidal Modeling

Does NOAA VDatum model adequately cover project to head of authorized navigation?
If NO, contact NOAA CO-OPS for possible extension of VDatum.

Has VDatum model been site calibrated/verified in the field?
If NO, perform field site calibrations.

If no VDatum coverage exists: Evaluate use of spatially interpolated model or NOAA TCARI model.

Has NAVD88-MLLW model file been generated for project?

Table 4-4 (Concluded). Tidal Reference Evaluation Factors.

IV. New Gaging Program Required to Develop Datum

Evaluate (with NOAA CO-OPS) options for using VDatum NAVD88-MLLW relationships
If not an option install a new gage to reestablish datum

Determine length of series requirements in coordination with NOAA CO-OPS	30 days most projects 90 to 360 days on critical clearance deep-draft projects

Were new reference tidal PBMs established and furnished to NOAA CO-OPS?

Do new reference PBMs need to be placed in the NSRS?

V. Hydraulic or Legacy Tidal Datums

Are legacy datums adequately referenced to the current MLLW datum?
If not, is estimated uncertainty documented?

In junctions between river and tidal datums, is the hydraulic low water plane adequately referenced to the NSRS and tidal datums?

Are local flood stages referenced to MLLW and NSRS?

CHAPTER 5

Procedures for Referencing Datums on Coastal Hurricane and Shore Protection Projects

5-1. Purpose. This chapter discusses the procedures to ensure hurricane protection projects and related shoreline protection structures (i.e., HSPP) are adequately connected and modeled relative to the National Water Level Observation Network (NWLON) tidal datum and the National Spatial Reference System (NSRS) orthometric datum established by the Department of Commerce. Coastal hurricane protection and shore protection structures include levees, floodwalls, breakwaters, jetties, groins, and dikes. Beach renourishment/restoration projects are also included in this category. Most of the guidance in Chapter 4 on coastal navigation projects is directly applicable to coastal hurricane and shore protection projects. Thus, references to Chapter 4 will be made where applicable.

5-2. Reference Datums and Tide Gage Connections. Most USACE shore protection projects have been designed relative to a sea level tidal datum—typically MLW or MSL referenced to a superseded legacy NGVD29 datum. Some projects may be defined relative to MHW. The designed protection grade will include allowances for storm surge, wave runup, tidal ranges, and other modeled factors used to develop a protection elevation. Uncertainties in these reference datums must also be considered in the design of protection elevations. Construction of shore protection projects is usually performed relative to a local orthometric datum, such as NAVD88. When RTK methods are used for construction stake out and machine control grading, NAD83/GRS80 ellipsoid references are required. As stated in preceding chapters, the main objective is to establish a firm relationship between the local orthometric and tidal datums at the project site, and that these datums (and any legacy reference datums) are referenced to the current NSRS and NWLON frameworks. For the vast majority of shore protection projects, modeling protection grades to the current tidal datum and NSRS/NAVD88 reference is relatively straightforward and normally requires minimal field survey effort.

a. Reference datums. Figure 5-1 illustrates the reference datums used for various shore protection projects. Design elevations of the beach renourishment berms or crests of the shore protection structures are computed relative to local tidal datums. This LMSL datum shown in Figure 5-1 must be based on nearby tide gages that relate LMSL to the NAVD88 datum. If no gages are near the project site, then the LMSL elevation at the project site relative to NAVD88 must be estimated using established hydrodynamically generated tidal models (e.g., VDatum). On existing projects originally referenced to a legacy reference datum (NGVD29 or MLW), the relationship between these datums and NAVD88 should be established. This assumes the original construction PBMs can be recovered. Stone placement on jetties or breakwaters, or grading of berms or hurricane protection levees, normally would be performed using RTK elevation measurements.

b. Primary Project Control Point (PPCP). All shore protection projects should have at least one primary NSRS bench mark from which all construction is referenced. This PPCP shall be published in the NSRS. On large beach renourishment or hurricane protection projects, more than one primary NSRS reference bench mark may be required. All projects shall have at least three PPCPs or LPCPs for use on construction plans. During Preconstruction Engineering and Design (PED), and prior to construction, the elevations of PPCPs and LPCPs shall have been checked internally—and regionally against other nearby NSRS points. Most coastal areas in CONUS have relatively dense NSRS network coverage (e.g., NGS level lines), from which the project can be directly referenced to this framework with minimal effort.

Figure 5-1. Reference datums on shore protection projects.

c. Tidal datum references. HSPP sites should be evaluated to verify (1) that the design/constructed sea level reference datum is current (i.e., latest tidal epoch and model) and (2) that this sea level datum can be related to the local NSRS orthometric datum (NAVD88) and the NAD83/GRS80 ellipsoid.

(1) If an active or historic NOAA tidal gage is situated in or near the HSPP area, data from that gage can be directly used to reference the project to the current tidal datum epoch. If the gage's tidal bench marks have not been connected to the NSRS orthometric datum, then GPS field surveys will be required to perform this connection. Only a small percentage of NOAA gage sites have tidal PBMs that have been connected to either NGVD29 or NAVD88. HSPP on remote coastlines may need static baseline GPS or CORS/OPUS observations to connect them to the NSRS. In general, CORS/OPUS methods described in Chapter 3 will provide sufficient accuracy to develop NAVD88 and tidal relationships on tidal bench marks at gages without published NSRS data.

(2) If there are no nearby tide gages, then the NAVD88-MSL relationship can be estimated using spatial interpolations between the nearest gages—see Appendix E. The local NAVD88-MSL relationship may also be estimated using NOAA VDatum models of the project region. If estimates are used, project documents must clearly describe the estimating procedure, uncertainties of the estimate, and potential impacts on the design (risk assessment) of the protection elevation of a control structure.

5-3. HSPP Elevation Accuracy Requirements. Table 5-1 lists general elevation accuracy requirements for HSPPs. This table should only be used as general guidance. Site dependent factors may require variations from this guidance.

Table 5-1. Survey Accuracies Common to Shore Protection Projects.

Bench Mark/Activity	Accuracy (95%)	Relative to
Primary Project Control Point (PPCP)	± 0.25 ft	Regional NSRS network
Local Project Control Points (LPCP)	± 0.02 to 0.05 ft	PPCP
Construction TBMs (hubs, nails, etc)	± 0.02 to 0.05 ft	LPCP
Construction grade stakes	± 0.1 ft	LPCP or TBMs
Levee or beach grading	± 0.5 ft	LPCP or TBMs
Offshore borrow area excavation	± 0.5 to 1 ft	PPCP
Offshore stone placement	± 0.5 to 1 ft	PPCP, LPCP, or TBMs

5-4. Shore Protection and Beach Renourishment/Restoration Projects. Shore protection projects are usually designed relative to tidal or orthometric datums, depending on local preferences. On many older projects, the relationship between orthometric and tidal datums is not firmly established. The PPCPs used to control the project should be related to the latest tidal datum and have a firm reference to the NSRS (NAVD88).

a. Control scheme for beach renourishment projects. Figure 5-2 depicts a survey control scheme that is set up for typical beach fill projects. Orthometric elevations of local LPCPs, PBMs, TBMs, grade stakes, and surveys are referenced to a PPCP that is published in the NSRS.

(1) Primary Project Control Point. Depending on the geographical scope of the project, one or more PPCPs may be needed. These PPCPs are used as RTK base stations to control grading operations (machine control), dredge borrow area surveys and excavation, setting grade stakes during beach fill operations, and controlling pre- and post-fill measurement & payment surveys. The NSRS connection will normally be performed following the same accuracy standards and field survey specifications outlined in Chapter 3—e.g., ± 0.25 ft. Checks between the PPCP and other NSRS bench marks are required prior to performing surveys.

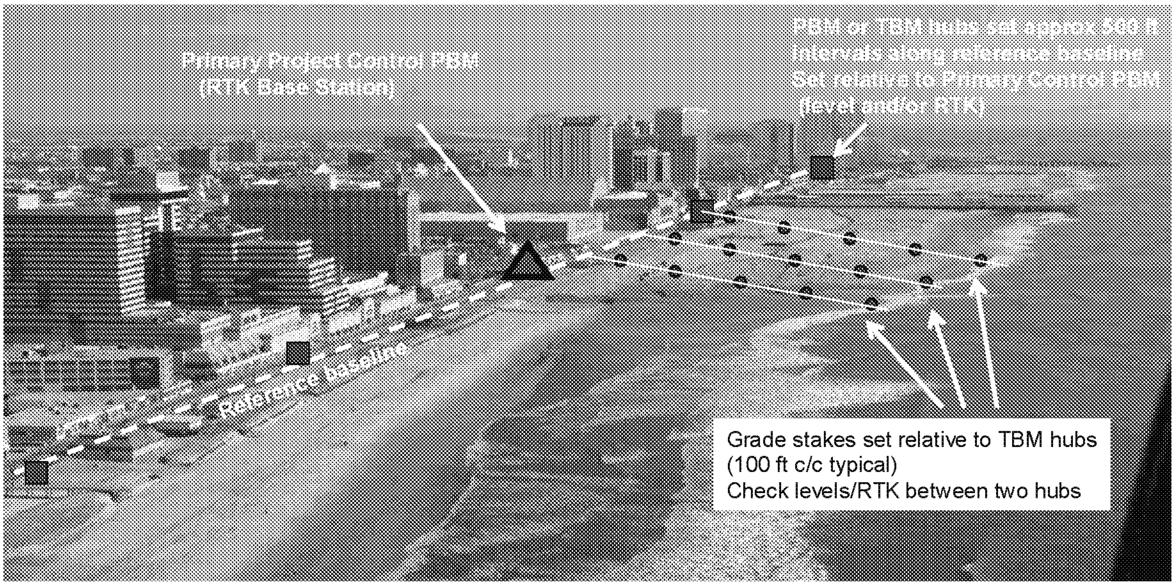


Figure 5-2. Beach renourishment project at Atlantic City, NJ. (Philadelphia District)

(2) Reference baselines. Most shoreline projects are continuously monitored by performing topographic and hydrographic surveys relative to established ranges. These ranges are referenced to a fixed baseline set back from the beach, and beach profile offsets are referenced to this baseline.

(3) Local reference PBMs. The baseline is usually referenced to local PBMs (LPCPs) set at various intervals. These LPCPs will have SPCS coordinates along with local station-offset coordinates. Vertical control on these baseline LPCPs may be referenced to legacy or local datums in order to monitor relative accretion or erosion at a measured profile. The LPCPs should be resurveyed at the beginning of a project. If the project specifications require holding legacy elevations on LPCPs, then any significant differences between these legacy elevations and the resurveyed elevations shall be clearly noted.

(4) Temporary reference or calibration hubs. In cases where no fixed LPCPs are available along the reference baseline, TBM hubs are established at various intervals. These hubs are used for controlling beach profile surveys—checking RTK calibration or for referencing level runs on individual beach profiles. Elevations on these hubs are normally surveyed by differential leveling relative to the PPCPs. Levels are run through local LPCPs and TBM hubs over the project reach. RTK elevation checks should also be made to verify site calibration and check for leveling blunders.

(5) Grade stakes. During beach fill operations, grade stakes are set from the reference LPCPs or TBMs. Either RTK, total station, or differential leveling methods are used. Elevation checks should be made to at least two fixed LPCPs or TBMs. The number of grade stakes on each profile will vary with the number of grade breaks on the project—see Figure 5-3. Grade stake elevation tolerances are normally specified as ± 0.1 ft relative to the reference LPCP or TBM. Grading tolerances are typically ± 0.5 ft.

b. Beach profile surveys. Beach fill measurement & payment surveys are normally performed at 100 ft c/c intervals. Spacing of periodic monitoring study profiles will vary between 200 ft and 1,000 ft. A design profile template is shown in Figure 5-3. Various topographic and hydrographic survey methods are used—see EM 1110-2-1003 (*Hydrographic Surveying*). These surveys are referenced to offsets from the reference baseline, or in some cases, an erosion control line, or construction setback control line. Profiles are run on established range azimuths. In Figure 5-3, the offset profile is referenced to a fixed local PBM for this section.

c. Reference datums. It is likely that older shoreline protection projects were designed and constructed relative to NGVD29 with the assumption that this datum approximated mean sea level (MSL). This NGVD29 is thus a legacy or local datum. These projects have likely been constructed and monitored relative to pre-set range monuments with a "locally "published" NGVD29 reference datum. Resurveys should document the updated relationships between the NAVD88 datum and the legacy datum. This is accomplished by comparing the updated NAVD88 elevation with the legacy NGVD29 elevations on recovered local bench marks.

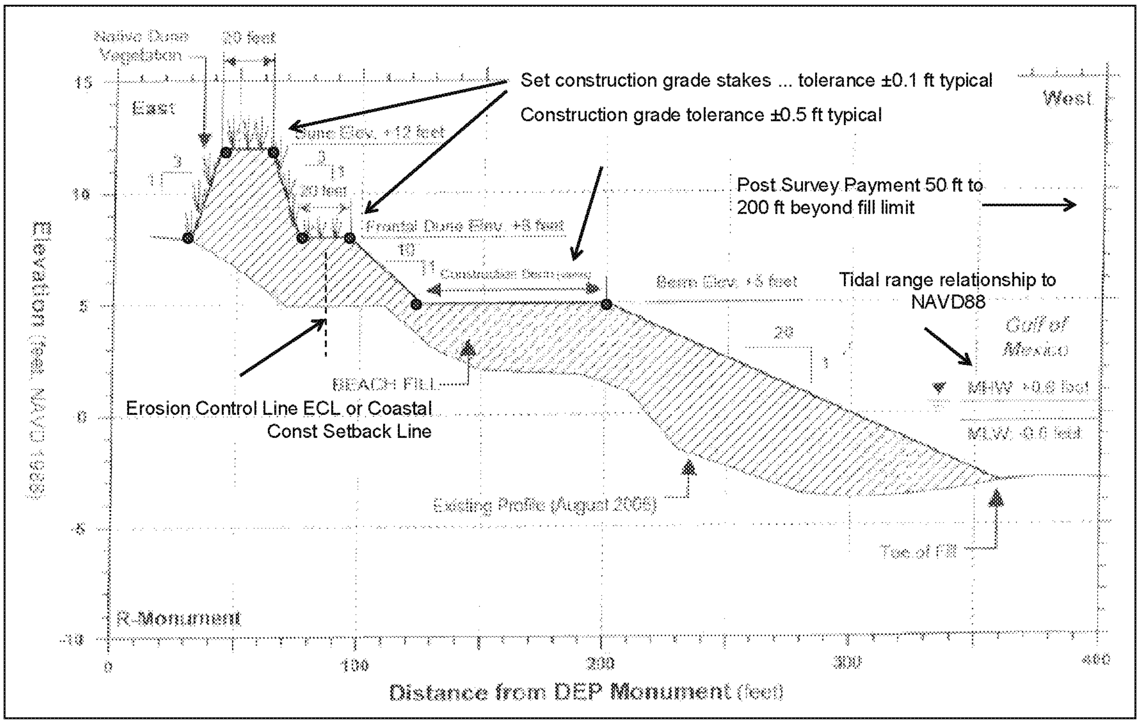


Figure 5-3. Beach profile template used for construction stake out and measurement & payment surveys.

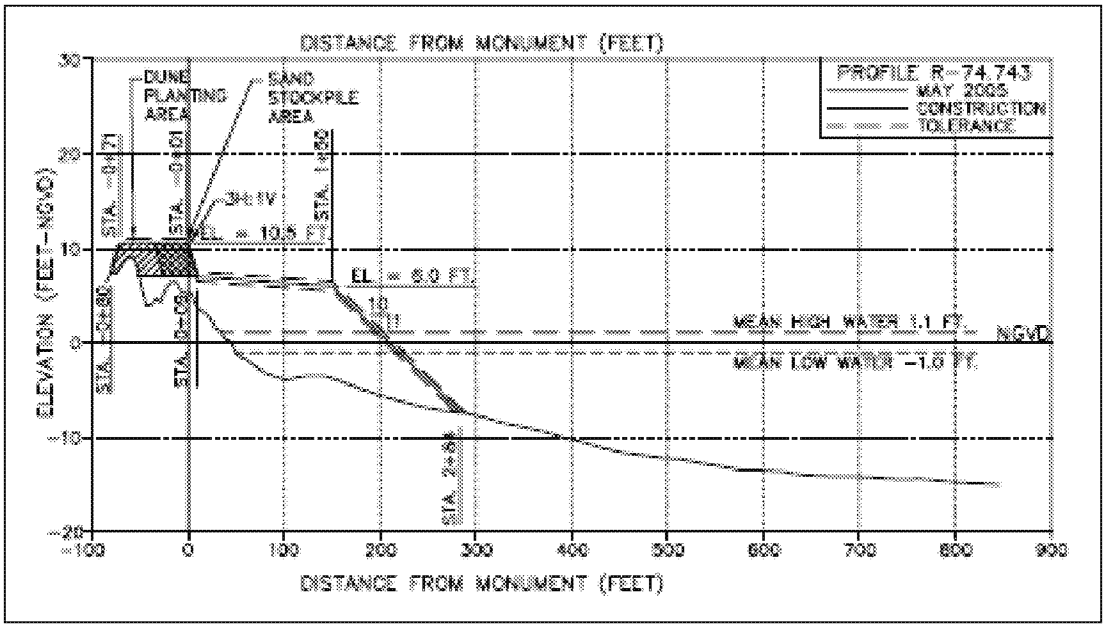


Figure 5-4. Beach profile template referenced to PBM R-74.743 on NGVD.

(1) NGVD29 datum references. In Figure 5-4, taken from construction plans, the "NGVD" elevation of the range monument "PROFILE R-74.743" was likely determined in 1974 when the range monument was set. The original or current relationship with the NSRS is probably unknown. Its "NGVD" relationship to MLW (-1.0 ft) or MHW (+1.1 ft) is likely based on the relationship at the nearest NOAA tide gage, which may be some 10 to 30 miles distant. The tidal epoch is not indicated in the drawing—a 0.25 ft to 0.5 ft tidal epoch difference may have occurred since the early 1970s. If the reference PBM and the NGVD/MSL design grade were not updated to reflect the relationship to the current tidal epoch, any new construction would be constructed 0.25 ft to 0.5 ft below the intended design elevation.

(2) Tidal datum relationships. Beach restoration projects are often distant from an established tide gage. The reference tidal datum may be estimated from nearby gages by spatial interpolation methods described in Appendix E. Such an interpolated tidal datum estimate is normally of sufficient accuracy. An interpolated tidal range between two NOAA gages would be reasonable if the tidal ranges at each gage do not vary significantly—for instance < 0.3 ft. Alternatively, if VDatum coverage exists in the area, this model may be used to estimate the relationship between MSL and the orthometric NAVD88 datum. Project documents must clearly document the source of any estimated relationships between orthometric and tidal datums.

d. Borrow area reference datums. Offshore borrow area elevations or depths should be referenced to the PPCP datum. Dredged excavation grades and borrow area surveys should be controlled by RTK or RTN measurements relative to, or calibrated from, this point. If the borrow area datum is referenced to a tidal datum (e.g., MLLW) then the relationship to the local NAVD88 datum must be documented.

e. Accuracy tolerances. Typical survey tolerances for shoreline protection projects are listed in Table 5-1.

f. Checklist. The following checklist may be used in developing control for a shoreline protection project.

(1) Is project referenced to a published NSRS control point (PPCP)?

(2) Has the PPCP elevation been checked against other published NSRS points?

(3) Are local project control points (LPCPs) firmly connected to the PPCP?

(4) Is the RTK base station situated at a PPCP or LPCP?

(5) Have beach profile reference monuments been set relative to the PPCP and LPCP?

(6) Are profile monuments correctly referenced to an established horizontal baseline?

(7) Have differential levels been run between all LPCP PBMs and range TBMs?

(8) Are leveled PBM and TBM elevations checked with RTK elevations?

(9) Is tidal datum relationship to NAVD88 established over the project site?

(10) Is the tidal datum based on current epoch?

(11) Are any legacy orthometric datums referenced to NAVD88?

g. Example application project—Fort Fisher, NC. Appendix G contains an example of a Wilmington District shore protection project that has been adequately referenced to the current NSRS orthometric datum and to the local tidal datum.

5-5. Breakwater and Jetty Construction Projects. Breakwaters and jetties constructed in tidal areas must be connected to both a local tidal design datum and NAVD88. Designed protection elevations are usually specified above MSL, although other reference tidal datums or legacy orthometric datums may be used (e.g., MLW, MHW, NGVD29). Construction and stone placement elevations will likely be referenced to NAVD88 and RTK methods used to monitor real-time placed elevations. Project control requirements to support construction and in-place surveys are the same as those required for shoreline protection projects described above.

a. Figure 5-5 depicts the control requirements for a jetty construction project. (A similar scheme would be laid out for a detached breakwater). A published PPCP needs to be established near the project site for use as an RTK base or RTN calibration. The elevation of this point is checked against nearby NSRS bench marks. Local control PBMs (LPCP) are then set inland from the jetty base. These points are surveyed relative to the PPCP using GPS or differential leveling. The LPCPs may be included in the NSRS or in the District's U-SMART database. Depending on the type of capping, access, construction requirements, etc, additional TBMs may be set in the stone along the jetty or detached breakwater.

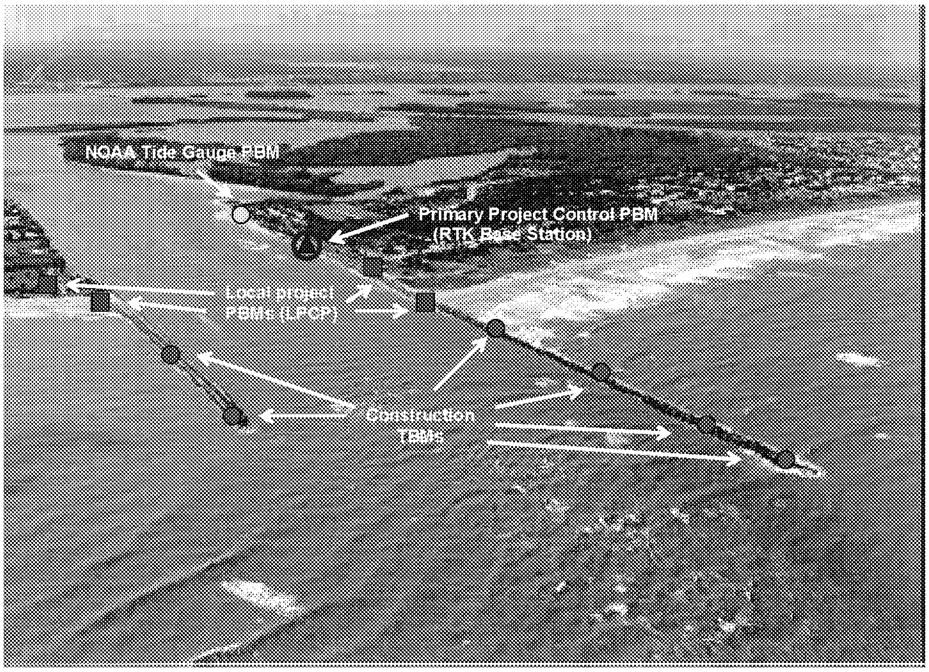


Figure 5-5. Project control requirements for jetty construction or maintenance.

b. The relationship between the orthometric and local tidal datum needs to be developed. In Figure 5-5, a NOAA gage is near the site and the connection between tidal PBMs and the PPCP can be made by GPS or differential levels. If no gage exists near the project site, then spatially interpolated or modeled (VDatum) estimates may be considered.

c. Breakwater monitoring surveys are often surveyed using a combination of subsurface multibeam hydrographic surveys and low altitude LIDAR airborne surveys. It is essential that the PPCP RTK base point for these surveys be the same point and both surveys be referenced to NAVD88 rather than tidal datums. In cases where acoustic returns are scattered by rock, lead line surveys may be required to measure voids.

5-6. Coastal Hurricane Protection Projects. Floodwalls, levees, seawalls, flood gates, pump stations, and related hurricane protection structures in coastal (tidal) areas require defined relationships between the design reference plane (normally MSL and stillwater surface elevations) and the local geodetic orthometric datum. This relationship must be established from a tidal gage at the project site or from hydrodynamically modeled spatial interpolations between tide gages. The latest geodetic, tidal datums, and tidal models established by NOAA must be used—and continually maintained and updated for epoch changes throughout the life of the project.

a. Reference tidal datum. Many hurricane protection project elevations have been designed relative to sea level datums based on interpolated or extrapolated references from gages—far and near. Depending on the type of gage, tidal range, and the distance from the gage, this interpolation or extrapolation may be valid—or sufficiently accurate—within ± 0.25 ft of the reference water level stillwater or surge design surface. Obviously, with sea level rise in many

CONUS coastal areas, the crest elevation of structures may be below that originally designed. In such cases, the original design documents should be checked to verify that allowance for sea level rise was considered in the design elevation.

b. NSRS connection. Connection to an NSRS orthometric datum need only be at the ± 0.25 ft accuracy level. This connection accuracy is usually adequate to relate protection heights to floodplain and first-floor elevations on a federally recognized reference system—e.g., NAVD88. Evaluated shore protection projects that are not on updated tidal and/or NSRS datums will require additional effort. In general, the updated sea level datum can be estimated by linear interpolation given sufficient NOAA or Corps gages exist in the region. The NSRS connection will normally be performed following the same accuracy standards and field survey specifications outlined in Chapter 3—differential leveling, static GPS baseline observations, or CORS/OPUS methods. At least one PPCP on each project shall have both a water level reference elevation and a NAVD88 elevation.

c. Example project: New Orleans to Venice Hurricane Protection Project. Figure 5-6 depicts local levee control PBMs along a portion of the Mississippi River below New Orleans to Venice, LA—West Plaquemines Levee District. Published NSRS PBMs ("N 367" and "J 370") are part of an older NGS level line that have updated time-dependent NAVD88 elevations—"NAVD88 (2004.65)."

(1) The BOOTHVILLE CORS ARP site provides real-time vertical control for GPS/OPUS observations in this region. The tidal bench mark at the Venice (Grand Pass) gage (876 0849 A TIDAL) is likewise connected to the NSRS network. These primary NSRS points provide direct PPCP control for this project area and no field surveys are required to establish additional points. Local levee control points (e.g., LPCP PIs) can be connected directly to these NSRS PPCP points using conventional survey methods, such as RTK. Levee profile elevations or cross-sections can be run directly from these PPCPs or LPCPs; however, given a Louisiana RTN covers this region, that network would be used for supplemental topographic surveys using the PPCPs for site calibration of the RTN.

(2) Since this area contains a LWRP hydraulic datum computation, this relationship between the LWRP to NAVD88 should be documented. The area also contains references to a legacy dredging datum—Mean Low Gulf (MLG). This estimated relationship must also be referenced to NAVD88.

(3) The datum relationships and uncertainties for an LPCP situated atop a levee can be tabulated as shown in Table 5-2. These relationships are based on survey observations from the NSRS network points to the LPCP. LWRP flow profile elevations are determined from interpolations between stage/discharge data at river gages that are referenced to NAVD88. The MLG datum is estimated from the Venice gage.

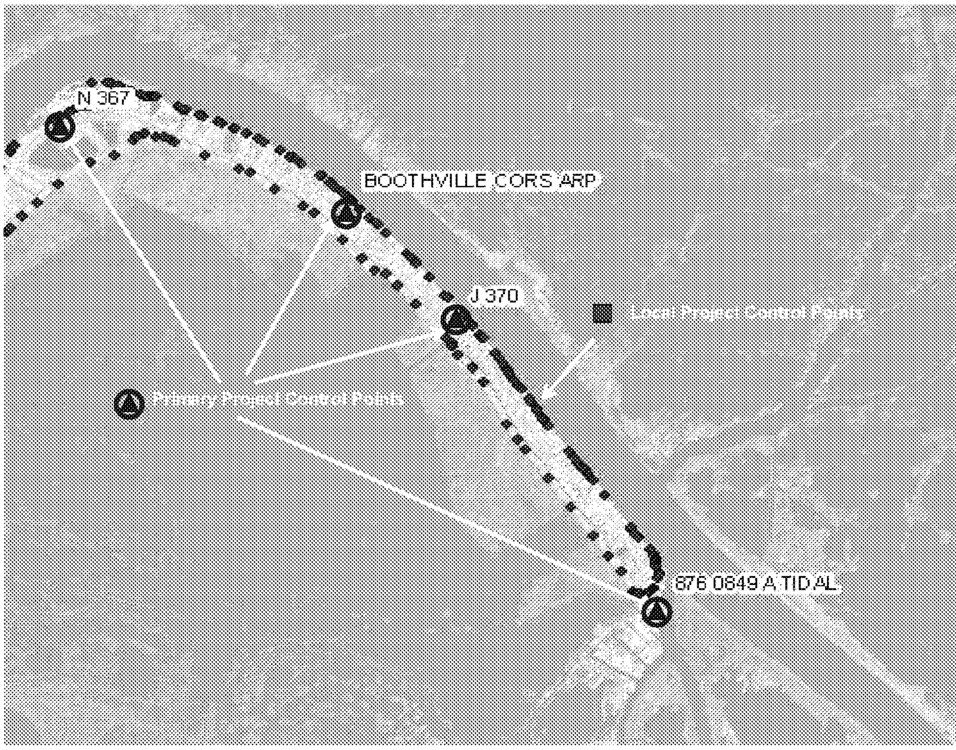


Figure 5-6. Mississippi River levee control connections with the NSRS and NOAA tide gage. Local project control points (LPCP) are connected with the PPCPs. (West Plaquemines Levee District)

Table 5-2. Elevations at a Baseline LPCP Station atop a Hurricane Protection Levee.

Datum	Elevation	Referenced From	Estimated Uncertainty	Relative to
LWRP 05	13.5 ft	River gage (interpolated)	± 0.2 ft	Profile
MSL	14.4 ft	NOAA gage 876 0849	± 0.2 ft	NWLON
LWRP 07	14.8 ft	River gage (interpolated)	± 0.2 ft	Profile
NAVD88 (2004.65)	14.93 ft	NSRS PPCP J370	± 0.05 ft	NSRS

Table 5-2 (Concluded). Elevations at a Baseline LPCP Station atop a Hurricane Protection Levee.

Datum	Elevation	Referenced From	Estimated Uncertainty	Relative to
MLLW	15.0 ft	NOAA gage 876 0849	± 0.2 ft	NWLON
NAVD88 (96)	15.0 ft	NSRS (superseded)	± 0.2 ft	NSRS
NGVD29 (98)	15.8 ft	Published NSRS	± 0.5 ft	NSRS
MLG	17.6 ft	Published NSRS (superseded NGVD29)	± 1 ft	NSRS
Ellipsoid	-64.27 ft	Geoid model	± 0.05 ft	NAD83/GRS80

d. Connection datums on miscellaneous hurricane protection structures. Elevations of floodgates, pump stations, and other structures need to be referenced to current orthometric datums and applicable legacy datums used in the original construction.

(1) Pump Station surveys. Figure 5-7 illustrates a method of determining updated elevations for a pump station. An LPCP is established near the pump station using static GPS techniques from published NSRS bench marks. A NAVD88 elevation is adjusted on the LPCP. Differential levels are run from the LPCP to a TBM or point inside the pump station that can be referenced on the as built drawings for the station—e.g., a floor elevation. An annotated photograph of the reference point is recommended, like that illustrated in Figure 5-7 for the Bayou Ducros #7 Pump Station. From this reference point, the NAVD88 invert elevations can be scaled from the as built drawings. If no as-builts are available, then invert elevations will have to be directly measured by leveling or total station—often a difficult process in confined spaces. If the pump station drawings are referenced to a local datum (e.g., New Cairo Datum (NCD) in the New Orleans area), then the NAVD88-NCD relationship is established. For example, in Figure 5-7 (Elmwood Canal Pump Station), given the first floor elevation is +15.20 ft NCD and the NAVD88 (2004.65) elevation is + 5.87 ft, the NCD-NAVD88 (2004.65) conversion factor is + 9.33 ft. Given the as built drawings show the pump invert elevation at +20.20 ft NCD, then the invert elevation is 10.87 ft NAVD88 (2004.65); computed from [20.20 ft – 9.33 ft]. If applicable, sea level datum references may also be included as an additional datum reference.

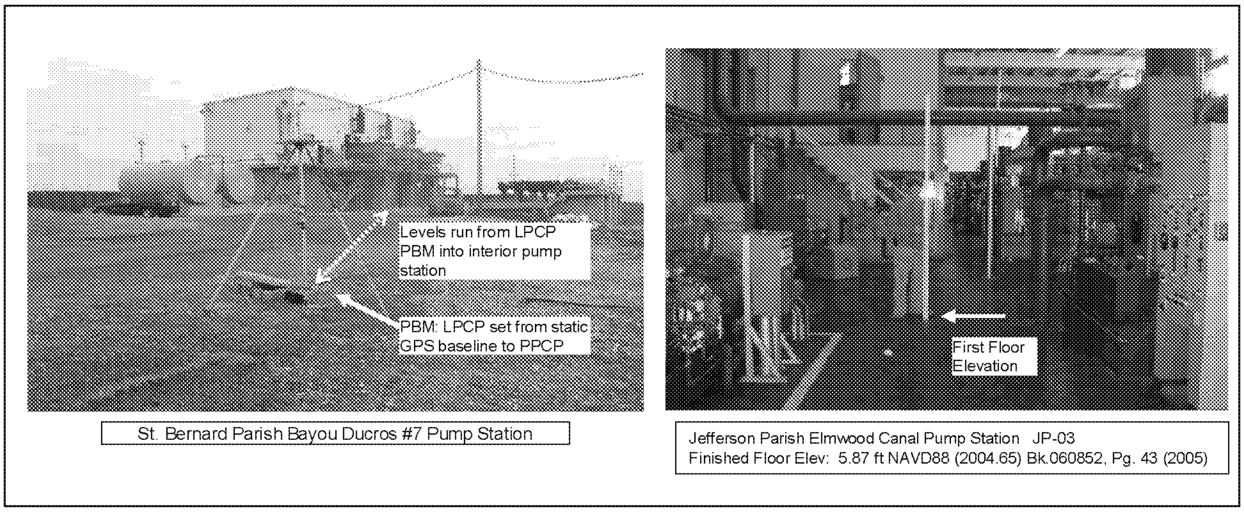


Figure 5-7. Referencing pump station elevations to NAVD88.

(2) Floodwall surveys. Figure 5-8 shows a cross-section of a hurricane protection I-wall on the New Orleans District's Inner Harbor Navigation Canal (IHNC) project. The topographic and hydrographic surveys of this section were performed relative to a local time-dependent NAVD88 datum, using RTK positioning from a NSRS PPCP. The top of wall elevation at this section shows both NAVD88 and Local Mean Sea level (LMSL) references.

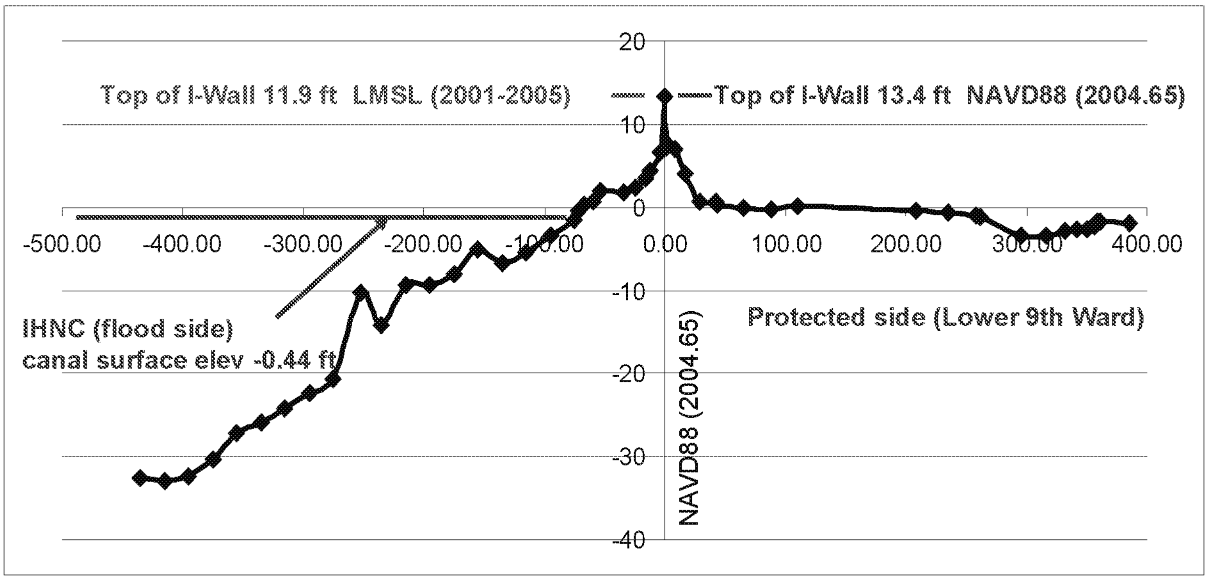


Figure 5-8. Referencing top of floodwall elevation to orthometric and sea level datums.

(3) Post hurricane high water mark (HWM) surveys. High water marks must be on a datum consistent with hydrodynamic surge models or other post-hurricane inundation studies. Therefore it is important that the reference datum used for HWMs be readily convertible to the model or study reference datum, such as LMSL. Using NAVD88 as a consistent reference is recommended, provided that the relationship between NAVD88 and LMSL can be estimated

throughout the region. Required accuracies of HWM elevations are dependent on the precision of the HWM, and the observer who estimated (marked) the HWM. Absolute field marking precisions of HWMs will range between 0.2 and 1 ft; thus, RTK survey methods are usually adequate. As shown in Figure 5-9, a TBM (stake or PK nail) is set in the vicinity of the HWM and a RTK (or fast static) elevation is placed on the TBM. Differential levels or total stations are then employed to survey the HWM on a wall or into the interior of a structure. HWM surveys, resultant elevations, and the reference datum must be clearly documented as shown in the figure.

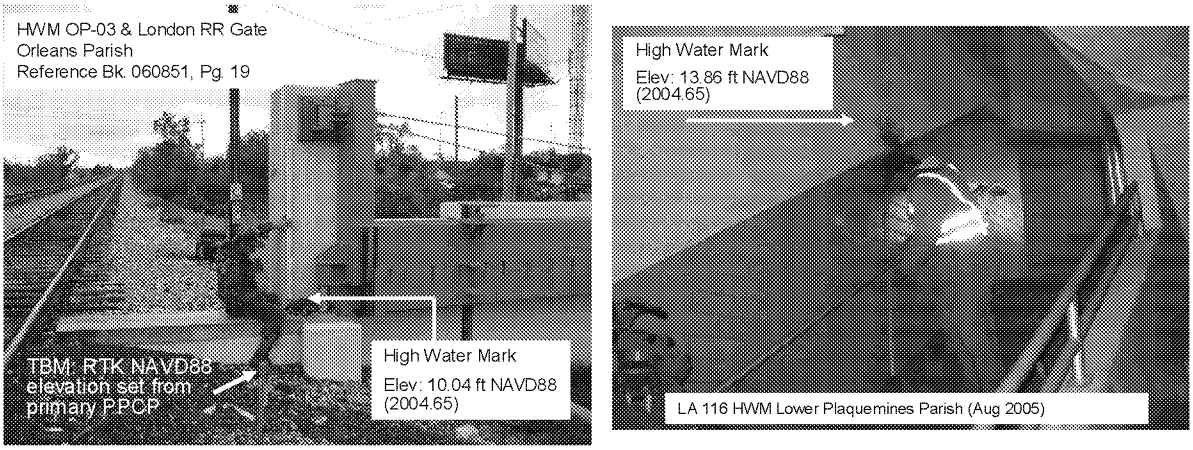


Figure 5-9. High water mark survey procedures and datum documentation.

(4) Monitoring elevations of floodwalls and bridge restrictions. In areas subject to hurricane surge, elevations of designed or constructed structures need to be surveyed. Figure 5-10 depicts topographic surveys of a floodwall intersection with a bridge floodwall. The reference LPCP elevation on the floodwall was positioned using static or fast-static DGPS methods from the surrounding primary control network. From this LPCP point differential levels were run to obtain the elevations of the floodgate, connecting I-wall, bridge floodwall, and the bridge low chord elevation. The LPCP should be described and placed in the District's control database (e.g., U-SMART). As with all HSPP structure surveys, photographic documentation of observed elevation points is recommended. The relationship between local MSL and legacy (constructed) datums may also be noted on the photo. The reference field survey book should always be included as this book will contain additional metadata as to the survey procedures, elevation datums, source PPCPs, etc.

EPA-002644

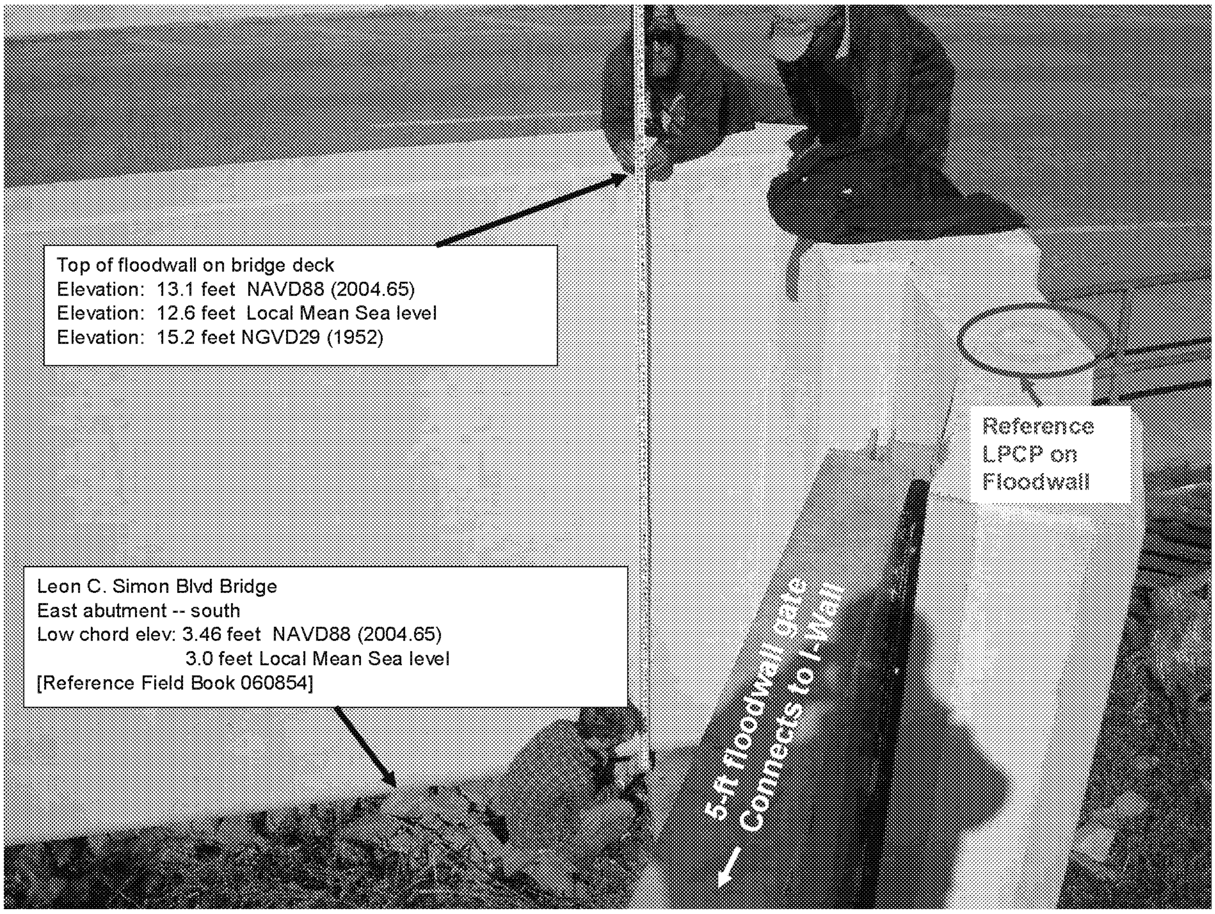


Figure 5-10. Surveying elevations of bridge chords, flood gates, and floodwalls.

CHAPTER 6

Procedures for Referencing Datums on Inland Flood Risk Management, Water Control, and Navigation Projects

6-1. Purpose. This chapter provides guidance for referencing project elevation grades on various inland flood risk management, water control, and navigation projects. Inland projects are defined as those with minimal or no tidal influence—their reference datums are defined relative to (1) modeled or measured hydraulic flows in rivers, (2) pool elevations in controlled reservoirs or between locks and/or dams, or (3) established reservoir and inland lake low water datums. This chapter outlines the field survey procedures needed to ensure these projects and their reference water level gages are adequately connected to the National Spatial Reference System (NSRS) orthometric datum established by the Department of Commerce.

6-2. Reference Grades on Inland Flood Risk Management and Water Control Projects. The relationship between geodetic and hydraulic datums on inland projects was outlined in Chapter 1 (Figures 1-2 and 1-3). In these figures, the relationships between the river stage, local gage, and terrestrial geodetic elevation(s) must be determined for each project. On river systems, these relationships are not constant, and vary spatially with the slope of the low water reference plane, design flood elevation, and geodetic datum readjustments. This relationship must be firmly established—either from direct river gage connections or from modeled hydraulic interpolations between gages.

a. Water surface elevation references. (See Chapter 2). The water surface elevation, or stage, is typically referred to a hydraulically based reference plane: e.g., Low Water Reference Plane (LWRP) in open flow rivers, or, in controlled areas, Project Pool, Low Water Pool, Normal Pool, Ordinary High Water Profile (OHWP), etc. The local river or pool gage may have its own reference datum from which flood stages are defined. The height of a levee or other water control structure is designed relative to predicted flood stage elevations on the river, along with other related design factors.

b. Flood protection or water control structure elevations. The reported elevation at the top of a floodwall, levee, or dam may have elevations based on more than one reference datum. The two minimum required reference elevations must include:

(1) Orthometric elevation directly referenced to current NSRS (NAVD88).

(2) Hydraulic elevation referenced to a defined reference plane (LWRP, pool, gage zero, etc.).

c. Other optional elevation references may include:

(1) Flood stage height reference.

(2) Ellipsoid height—based on local NSRS geoid model—useful for performing RTK topo surveys.

(3) Base Flood Elevation (BFE) reference—from local studies or models.

(4) NGVD29 elevation—usually based on older reference monuments or as-built drawings.

(5) Local USACE legacy datums—e.g., Cairo Datum, Sea Level Datum, MSL 1912.

d. Elevation uncertainties. Figure 1-2 in Chapter 1 illustrated the uncertainties in vertical datums on an inland flood risk management project. Each reference datum listed above has some statistical uncertainty level that must be considered in protection reliability, risk assessment models, and levee/floodwall certification. These datum uncertainties must be estimated for each project. NSRS (NAVD88) regional relative accuracy estimates may be obtained from NGS observation adjustment statistics. These NSRS uncertainties propagate down to local project control point (LPCP) elevations and then to topographic surveys of project grades. Methods for estimating the propagated uncertainties of elevation grades are described in Chapter 9. The accuracy of local hydraulic stage/flowlines may be more difficult to estimate—see Section 6-4. Pool or reservoir stage elevations (and local low water datums) are usually well defined based on long-term gage data. Legacy datum references (e.g., NGVD29) may have highly uncertain accuracies and origins.

e. River gage NSRS (NAVD88) elevation connection requirements. Figure 6-1 depicts a river gage connection to a floodwall cap elevation—shown here to a PBM set atop the wall. In this example, a river gage on LWRP or pool datum is connected with the regional NAVD88 network; thus providing an external (i.e., ellipsoidal and orthometric) reference for the gage, along with the LWRP or pool hydraulic profile reference for the floodwall cap. The relationship between the orthometric height, ellipsoidal height, geoid height, and the hydraulic elevation is shown.

(1) In the top part of Figure 6-1, a level run from the gage reference point (20.0 ft) established an elevation on the top of the I-wall at 40.35 ft (LWRP).

(2) In the lower part of Figure 6-1, differential GPS observations measured an ellipsoid height of 278.02 ft at the PBM atop floodwall. Given a published geoid height of (-) 94.03 ft for this area, the orthometric NAVD88 elevation of 372.05 ft is determined using the relationships outlined in Chapter 2.

(3) The NGVD29 elevation shown in Figure 6-1 (371.76 ft) is based on a modeled (VERTCON or CORPSCON) difference of 0.29 ft from NAVD88. This modeled relationship may be accurate to only ± 0.5 ft, depending on many factors. Legacy or local datums maintained on floodwalls, such as NGVD29, should always be caveated with appropriate metadata, to include estimated age, reliability, and accuracy.

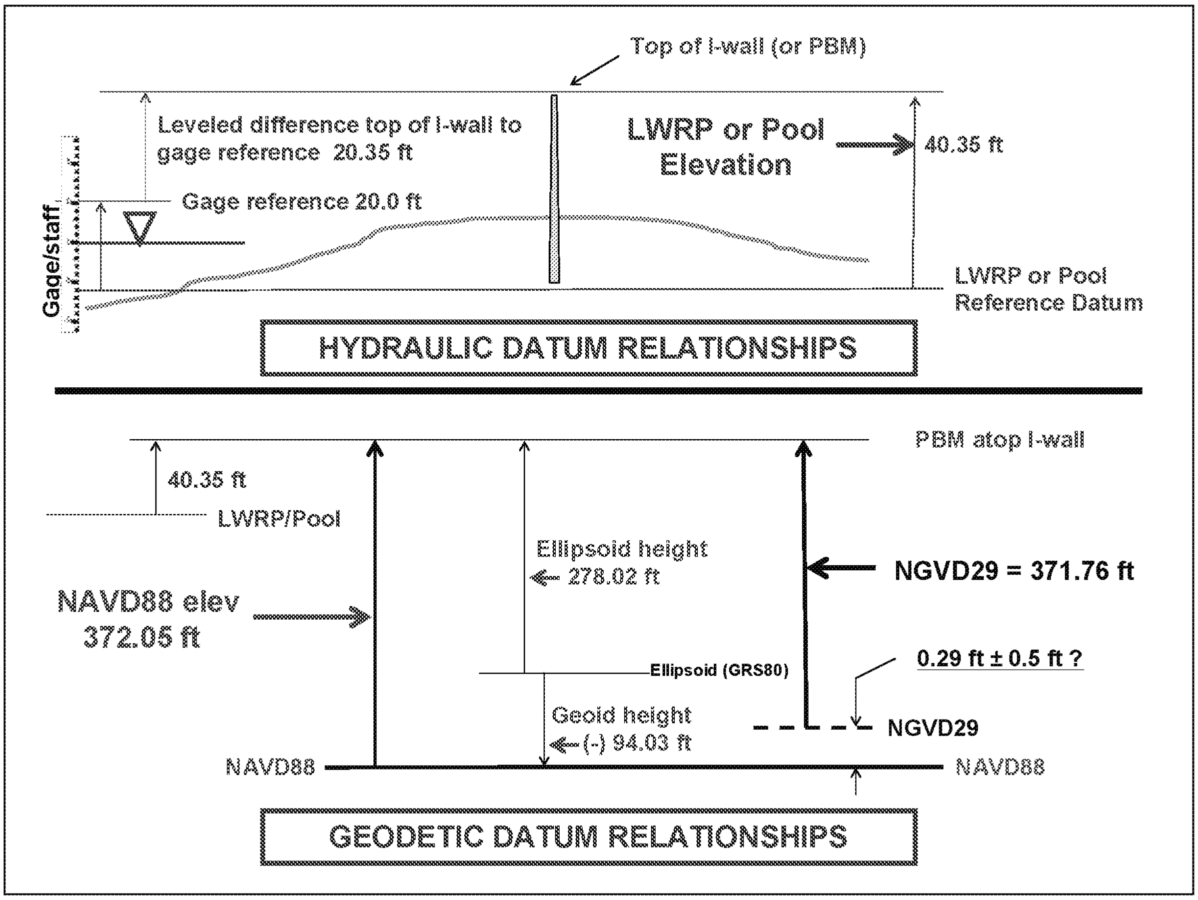


Figure 6-1. Orthometric height and hydraulic reference datum relationships on a floodwall.

6-3. Procedures for Connecting Inland River, Pool, or Reservoir Gages to the National Spatial Reference System. Inland river gages that are used to reference and model USACE floodwall design elevations should be firmly referenced to NAVD88, and be included within the NSRS. This is intended to insure these gages are on the same regional (nationwide) vertical datum used for hydrologic and hydraulic studies performed by USACE and other agencies. Gages referenced to unknown, legacy, or superseded datums (e.g., MSL 1912, NGVD29) must also be referenced to NAVD88.

a. Reference bench marks at river gages. A minimum of three bench marks shall be established around a river gage that is used to reference flood protection elevations on nearby levees or floodwall systems. Only one of these reference points needs to be connected to and published in the NSRS, using either CORS baseline observations, differential levels, or DGPS baseline observations (e.g., static or fast/rapid static methods). The remaining river gage bench marks and the gage zero reference can be surveyed using Third-Order differential leveling methods from the primary bench mark. Data for the gage's primary reference mark (PPCP) shall be incorporated into the NSRS database.

b. Reference bench mark descriptions—periodic inspections. The description for the gage's reference bench mark must contain, in addition to the standard location data, full metadata associated with that bench mark and its nearby river gage. For example:

Bench Mark:	*USED RIVER GAGE 12345 1955*
River Gage:	*[River gage name/file designation]*
Elevation:	*419.63 ft NAVD88 ± 0.22 ft [2008 03 21 adjustment]*
Elevation:	*40.35 ft above LWRP 20XX [2008 03 21]*
Elevation:	*20.35 above river gage zero reference [2008 03 21]*
Elevation:	*3.38 ft above 12345 RM 1 [2008 03 21]*
Elevation:	*0.97 ft below 12345 RM 2 [2008 03 21]*
Position:	*[SPCS X & Y location/accuracy/date]*
Source:	*[specify NGS "PID" and District file number]*

Subsequent bench mark "Recovery Notes" made at periodic (e.g., semi-annual, annual, biannual) gage inspections should also update the gage reference and adjacent reference bench mark connections. The NSRS datasheet in Figure 6-2 contains a simulated example of an inspection recovery note made for a reference bench mark at a river gage. The last gage inspection in 2009 noted that levels were run between the gage and reference bench marks. The results and differences from the 2008 elevations are included on the description. This example utilizes the NSRS for recording gage inspection recoveries in that the reference bench mark is published. Other documentation formats for gage inspections may also be used—e.g., U-SMART (see Chapter 3). An example U-SMART description for an inflow gage in Pittsburgh District is shown in Appendix H.

```
XX999  DESIGNATION -  CEMVS GAGE 12345 RM 1
XX999  PID         -  XX999
XX999  STATE/COUNTY-  MO/C OF ST LOUIS
XX999  USGS QUAD   -  GRANITE CITY (1998)
XX999                         *CURRENT SURVEY CONTROL
XX999  ________________________________________________________________________
XX999* NAD 83(1986)-  38 00 00.     (N)     090 00 00.     (W)      OPUS
XX999* NAVD 88     -       127.903  (meters)      419.63   (feet)   ADJUSTED
XX999  ________________________________________________________________________
XX999  GEOID HEIGHT-         -31.08  (meters)                       GEOID03
XX999  DYNAMIC HT  -         127.821 (meters)      419.36  (feet)   COMP
XX999  MODELED GRAV-     979,991.3   (mgal)                         NAVD 88
XX999  VERT ORDER  -  FIRST     CLASS II

XX999                          STATION DESCRIPTION  (2008)

XX999'DESCRIBED BY USAED ST LOUIS 2008 03 21 (R MESKO)
XX999'IN ST LOUIS, 1.35 KILOMETERS (0.85 MILE) SOUTH ALONG THE FLOOD WALL OF
XX999'THE MISSISSIPPI RIVER FROM THE GOLDEN ARCH BRIDGE OVER THE RIVER, SET
XX999'VERTICALLY IN THE EAST END OF THE ONLY LARGE SOLID PIER OF A RAILROAD
XX999'OVERPASS THAT LEADS WEST OVER THE TRACKS THAT PARALLEL THE FLOOD WALL,
XX999'AND 19.21 METERS (63.0 FEET) WEST OF THE WEST FACE OF THE FLOOD WALL.
XX999'THE MARK IS THE PRIMARY REFERENCE POINT FOR COE RIVER GAGE NO. 12345
XX999'WHICH IS APPROX 30 FT NORTH OF THE MARK.
XX999'THE MARK IS 1.04 METERS N FROM A WITNESS POST.
XX999'THE MARK IS 1.12 M ABOVE GROUND.
XX999'RIVER GAGE NO 12345 LEVELING REFERENCES RUN 2008 03 21
XX999'THE MARK IS 20.35 FT ABOVE THE ZERO GAGE REFERENCE POINT
XX999'THE MARK IS 40.35 FT ABOVE LWRPXX
XX999'THE MARK IS 3.38 FT ABOVE 12345 RM 2, A COE DISC LOCATED ON THE
XX999'FLOODWALL 45.6 FT NORTH.
XX999'THE MARK IS 0.97 FT BELOW 12345 RM 3, A COE DISC LOCATED ON THE
XX999'FLOODWALL 89.4 FT SOUTH.

XX999                          STATION RECOVERY (2009)

XX999'RECOVERY NOTE BY USAED ST LOUIS 2009 06 05 (R MESKO)
XX999'RECOVERED MARK AND RM1 AND RM2 IN GOOD CONDITION, AS DESCRIBED.
XX999'RELEVELING RESULTS FROM 2009 06 05 GAGE INSPECTION:
XX999'THE MARK IS 20.34 FT ABOVE THE ZERO GAGE REFERENCE POINT
XX999'THE MARK IS 40.34 FT ABOVE LWRPXX
XX999'THE MARK IS 3.39 FT ABOVE 12345 RM 2, A COE DISC LOCATED ON THE
XX999'FLOODWALL 45.6 FT NORTH.
XX999'THE MARK IS 0.97 FT BELOW 12345 RM 3, A COE DISC LOCATED ON THE
XX999'FLOODWALL 89.4 FT SOUTH.
```

Figure 6-2. Simulated NSRS datasheet with gage inspection recovery notes.

6-4. <u>Elevation Accuracy Requirements at Reference Gages</u>.

a. Hydrological and hydraulic accuracy requirements. In order to best define the governing accuracy standard required for connecting primary project control monuments to the regional NSRS, it is necessary to understand the hydraulic engineering requirements and applications for such connections. River, pool, or reservoir gages normally have highly accurate local datums—i.e., at the gage itself. However, the absolute vertical relationship between adjacent gages is often uncertain, as was illustrated in Figure 1-2. For example, two river gages separated by 20 miles may have been referenced to orthometric datums 50 years ago—e.g., SLD29 or NGVD29. Surveys were never performed directly connecting the reference bench marks at these gages. The uncertainty between the connections could exceed 0.5 ft or more—see "*Mapping the Zone: Improving Flood Map Accuracy*" (NRC 2009). Calculated water surface profiles could also vary by as much as foot or more, depending on numerous factors. These uncertainties and variations need to be considered in defining relative NSRS accuracy requirements for reference bench marks at a gage. The following excerpt from NRC 2009 illustrates the considerations needed in determining the NSRS accuracy requirements for adjacent river gages:

> "*...frequency analysis of stage height is not the same thing as frequency analysis of base flood elevation because the BFE is defined relative to an orthometric datum [NAVD88] ... and the stage height is defined relative to an arbitrary gage elevation datum. However, it is not necessary to reconcile these datums because what we are seeking is not the elevation itself, but rather the uncertainty of the elevation. The difference between the stage height and the flood elevation is the fixed datum height that is the same for all measurements and thus does not affect their variations from year to year.*"

The nominal ± 0.25 ft relative accuracy standard in Table 3-1 is believed to be adequate for most USACE projects; fully considering hydraulic design models, design criteria, construction tolerances, and other federal and state agency accuracy requirements.

b. Accuracy estimates. Region-wide hydraulic accuracy requirements can also be estimated using the guidance in "*Accuracy of Computed Water Surface Profiles*" (HEC 1986). This study assessed the survey accuracy required to achieve desired profile accuracies, as illustrated in Table 6-1.

Table 6-1. Survey Accuracy Requirements[1] for Specified Profile Accuracies. (HEC 1986)

Stream Slope (ft/mile)	Profile Accuracy Emean[2] (ft)	Manning's n-value reliability $N_r = 0$: Aerial Survey Contour Interval	Manning's n-value reliability $N_r = 0$: Topo Map Contour Interval	Manning's n-value reliability $N_r = 1$: Aerial Survey Contour Interval	Manning's n-value reliability $N_r = 1$: Topo Map Contour Interval
1	0.1	10 ft	n/a	n/a	n/a
1	0.5	10 ft	5 ft	n/a	n/a
1	1.0	> 10 ft	10 ft	10 ft	2 ft
1	1.5	> 10 ft	10 ft	10 ft	5 ft
1	2.0	> 10 ft	10 ft	>10 ft	10 ft
10	0.1	2 ft	n/a	n/a	n/a
10	0.5	10 ft	5 ft	n/a	n/a
10	1.0	10 ft	5 ft	10 ft	n/a
10	1.5	> 10 ft	10 ft	10 ft	2 ft
10	2.0	> 10 ft	10 ft	10 ft	5 ft
30	0.1	2 ft	n/a	n/a	n/a
30	0.5	10 ft	2 ft	n/a	n/a
30	1.0	10 ft	5 ft	10 ft	n/a
30	1.5	> 10 ft	10 ft	10 ft	2 ft
30	2.0	> 10 ft	10 ft	10 ft	5 ft

[1] Denotes maximum survey contour interval to produce desired survey accuracy
[2] Emean is "mean absolute reach error"

c. From Table 6-1, given the allowable error in a water surface profile, and considering other hydraulic factors, the required accuracy of topographic data (e.g., stream cross-sections) can be estimated. Topographic survey accuracies in this older publication are defined relative to a National Map Accuracy Standard (NMAS) contour interval parameter. These can be converted to NSSDA 95% confidence standards. HEC 1986 should be reviewed in order to appreciate the impact (or often lack thereof) of survey accuracy on computed water surface profiles. For example, if a hydrological or hydraulic water surface profile model is sensitive to cross-sectional accuracy at the ± 2 ft (NSRS) level, there would then be no point in requiring control points for these sections to be accurate to the ± 0.1 ft (NSRS) level.

d. Regional gage accuracy for levees and related flood protection projects. The Bois Brule Levee and Drainage District in St. Louis District represents a typical main-stem Mississippi

River levee system (see Appendix I). On this levee segment the river slope drops approximately 13 ft over a 12-mile reach. Given the magnitude of the elevation change over this 12-mile distance, the design levee grades between each end of the system would not need a high level of accuracy relative to the NSRS. A ± 0.25 ft to ± 0.5 ft relative accuracy between the northerly and southerly limits would be adequate for most engineering purposes. These levels of accuracy can be easily achieved with static DGPS, CORS/OPUS, or conventional differential leveling methods.

e. Gage accuracy requirements in low gradient areas. Many floodplain areas with minimal water surface gradients will require more accurate elevation connections with the NSRS in order to measure flow or inundation conditions. An example is the Jacksonville District's Central and Southern Florida (C&SF) project that contains a vast network of levees, canals, control gates, pump stations, and other control structures throughout southern Florida; including portions of the Everglades. In some cases, elevation differences over a few miles may be only 0.2 ft. To provide a consistent geodetic reference framework for this project, the USACE and NGS performed high accuracy "height modernization" control surveys at hundreds of PBMs throughout the region. These geodetic surveys included a network of static GPS baselines and high-order differential leveling. Geodetic survey standards followed NGS specifications and resultant "PPCP" data were adjusted and published by the NGS—see "*Guidelines for Establishing GPS-Derived Ellipsoid Heights (Standards: 2 cm and 5 cm)*" (NOAA 1997) and "*Guidelines for Establishing GPS Derived Orthometric Heights (Standards: 2 cm and 5 cm) version 1.4* " (NOAA 2005). These NSRS PPCPs were subsequently used to establish LPCP elevations near gages and pump stations.

6-5. <u>Levee System Connections to the NSRS</u>. The following guidelines are recommended procedures to establish PPCPs suitable for defining project elevations relative to the NSRS. They are based on the nominal target accuracy standard of ± 0.25 ft relative to the published NSRS. Field survey methods for performing the connections were covered in Chapter 3. These guidelines are also applicable to other water control and inland navigation projects covered in this chapter.

a. General PPCP requirements. Each levee project or segment should have at least one PPCP that has been connected to the NSRS. On large levee projects, PPCPs should be spaced between 15 to 20 mile intervals. This recommended spacing is dependent on local RTK or RTN capabilities, district survey standards, and the distance from the PPCP to the levee. In general, the PPCP should be located relatively close to the project in order to establish supplemental LPCP connections using GPS static or rapid static baseline methods—see Figure 6-3. If the project is covered by an RTN, then a less dense network of PPCPs will be required for RTN site calibration. When multiple PPCPs are established on a levee segment, it is recommended that these PPCPs be interconnected with static GPS baseline observations, along with observed baselines to nearby CORS points.

b. Supplemental LPCPs. LPCPs on a levee segment are connected with the PPCPs using the various survey methods described in Chapter 3. The density of LPCPs is site dependent. In general, static or RTK techniques are most efficient to perform this connection. Descriptions for these points should be included in a district project control database (e.g., U-SMART) for permanent retention. The NSRS elevations determined for these LPCPs should not supersede local construction or legacy elevations—see Chapter 3.

c. Water level gage connections. Reference PPCP bench marks need to be set near each water level gage associated with a levee system or water control project. These gage reference marks will be designated as "Primary Project Control Points" and will be connected to the NSRS using any of the methods covered in Chapter 3. Level ties between the gage reference PBMs are also required and elevation differences and associated metadata should be included in the NSRS bench mark description or the U-SMART database system.

d. Bench mark construction. Bench mark construction for new PPCPs and LPCPs points will follow the guidance in EM 1110-1-1002 (*Survey Markers and Monumentation*). Type C (USACE disk set in existing concrete structure) marks are recommended. Type F and Type G marks (disk attached to shallow rod or rebar), or other suitable type marks/monuments, are also acceptable as bench marks. Geodetic survey quality deep-driven mark stability is not required. At least three reference bench marks are required at each gage.

e. Summary of PPCP and LPCP connections. Figure 6-3 summarizes the general NSRS connection requirements for PPCP control on a levee segment. PPCP elevations were established by GPS or leveling observations to surrounding NSRS bench marks. LPCP connections with the PPCPs are also indicated. Topographic site plan surveys would be performed relative to the nearest LPCPs on the levee.

f. Application projects. The following appendices contain examples of USACE inland projects that have been connected to the NSRS.

(1) Appendix H. East Branch Clarion River Dam and Spillway Control Surveys (Pittsburgh District),

(2) Appendix J. Establishing NSRS Elevations on 15 Dam and Reservoir Projects in Pittsburgh District.

(3) Appendix I. St. Louis District: Control Surveys--Bois Brule Levee and Drainage District.

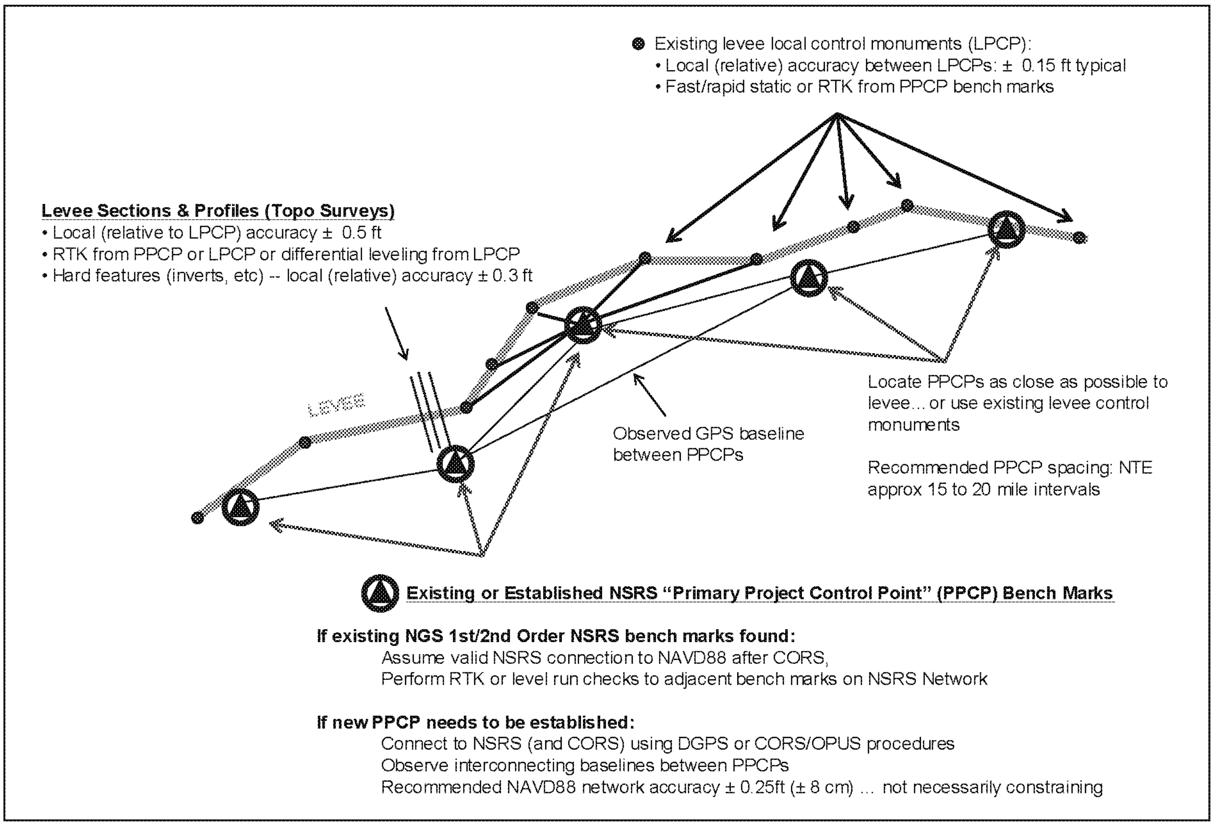


Figure 6-3. NSRS and local reference bench marks on a levee system.

6-6. Dam and Reservoir Connections to the NSRS. For most dam projects, multipurpose hydropower projects, and related impoundment reservoirs, only one PPCP needs to be tied in to the NSRS, as illustrated in Figure 6-4. This point will usually be one of the deformation and settlement monitoring bench marks used on periodic inspection surveys. NSRS referenced elevations for all the other monitoring points can be computed from the elevation differences in the most recent periodic inspection report—these differences are generally accurate to 0.005 ft tolerances when precise geodetic leveling techniques are employed. The PPCP at a dam and reservoir project can be referenced to the NSRS using the survey techniques covered in Chapter 3. In general, CORS/OPUS observations will be adequate to provide a reliable reference to the NSRS. In some instances, networked baseline connections may be selected.

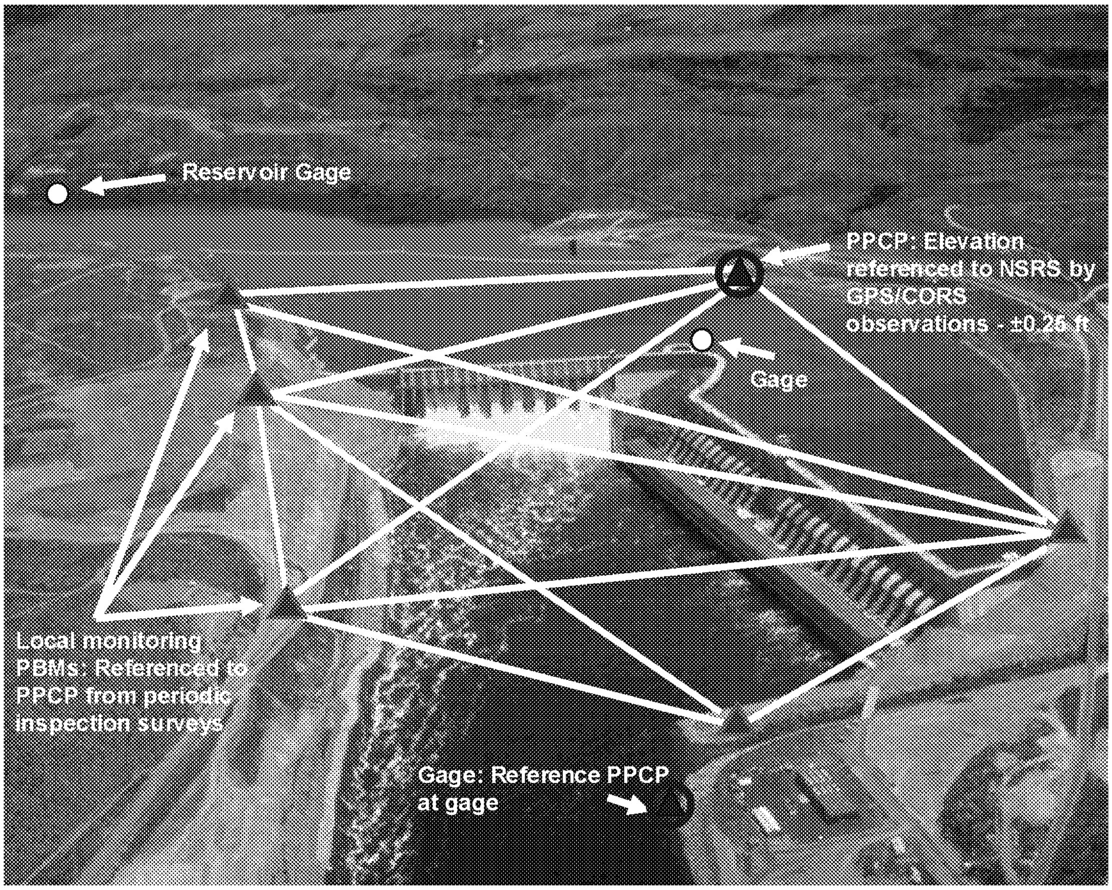


Figure 6-4. NSRS connections at a multipurpose hydropower project.

a. The guidance in this section is not intended to modify local datums used on periodic deformation monitoring inspections or for water control purposes. The intent is to add a reliable NSRS reference to these structure points and any gages near the dam and reservoir. This allows pool, intake, spillway, and crest elevations to be externally referenced to the current NSRS reference datum. The nominal ± 0.25 ft relative NSRS accuracy will normally be suitable for most projects. Exceptions may exist for large impoundment reservoirs. Detailed guidance for monitoring relative elevations around dams is covered in EM 1110-2-1009 (*Structural Deformation Surveying).*

b. Vertical settlement monitoring networks are often referenced to an arbitrary datum—i.e., 100.00 ft or 1,000.00 ft at the primary reference point held fixed in the network. Relative elevation accuracies (not NAVD88 accuracies) are most critical. For example, a monitoring plug on a concrete monolith may have a local vertical precision of ± 0.001 ft relative to an adjacent monolith plug, and perhaps ± 0.005 ft relative to the external monitoring network some 500 ft to 1,000 ft distant. In many cases, the monolith point is also referenced to a superseded legacy vertical datum, such as NGVD29. Thus, a monolith plug could have two defining elevations—e.g., 104.678 ft on the deformation monitoring network datum and 786.3 ft (± ? ft) on the legacy NGVD29 datum. Once the network is updated to the NSRS, the NAVD88 elevation for this same monolith point might be 784.82 ft ± 0.2 ft. This NSRS elevation may have been obtained from static GPS baseline observations to NSRS points 5 to 10 miles distant, and/or CORS points 50 to 150 miles distant.

c. Gages near the dam or in the reservoir must also be referenced to the NSRS elevation datum. Procedures and documentation are similar to that required for levee projects in the above paragraphs. The relationships with legacy orthometric datums and reservoir pool datums must be documented at each gage.

d. Appendix H contains an example of geodetic surveys that were performed to establish primary project control on Pittsburgh District's Clarion River (East Branch) Dam and Spillway. See also Appendix J.

6-7. Inland Navigation Lock and Dam Connections to the NSRS. Inland lock structure elevations (and related gate structures, sills, guide walls, dams, etc.) are connected to the NSRS similarly to dam and reservoir projects described above. Figure 6-5 depicts a control scheme for a typical lock structure. Upstream and downstream gages should be referenced to the NSRS at this lock. As with dam and reservoir projects described above, NSRS (NAVD88) elevations will not supersede local construction, water control, or deformation monitoring elevations on LPCPs used at the site. The relationships between NAVD88 and legacy orthometric datums and controlled pool datums upstream and downstream of the lock must be documented at each gage.

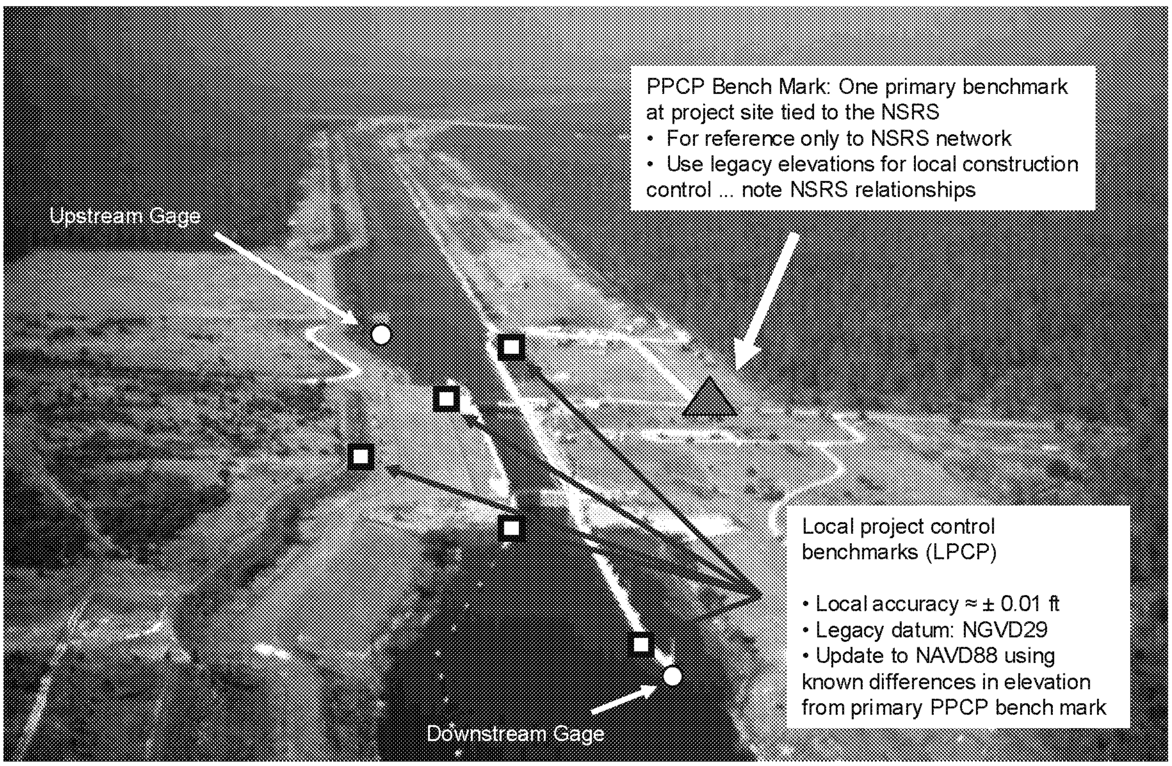


Figure 6-5. NSRS connections at an inland lock project.

6-8. Referencing Projects on the Great Lakes and Connecting Waterways. Navigation and shore protection projects on the Great Lakes and connecting waterways are referenced to the International Great Lakes Datum (IGLD). IGLD is specified by the year of the adjustment (currently 1985). Each of the five Great Lakes has its own independent IGLD low water reference datum, as listed in Chapter 2 (Table 2-2). The IGLD85 and its relationship to NAVD88 is determined and defined by the International Joint Commission—see "*Establishment of International Great Lakes Datum--1985*" (IJC 1995). IGLD elevations of bench marks are published in the NSRS.

a. The datum references in the connecting channels (i.e., Niagara, Detroit, St. Clair, and St.Marys Rivers) between the fixed datums at each lake are developed by the local USACE districts. See a complete listing in Appendix K.

b. Primary project control point connections to the NSRS (i.e., IGLD85 or NAVD88) would follow similar guidance outlined for navigation, shoreline protection, and flood risk management projects in this manual.

c. Both NAVD88 and IGLD85 are referenced to the same primary bench mark at Pointe-au-Père/Rimouski, Quebec. The only difference is that the IGLD85 elevations are published as dynamic heights and the NAVD88 elevations are published as Helmert orthometric heights.

d. Due to inaccuracies in NAVD88 leveling adjustments in the Great Lakes region, a "hydraulic corrector" must be applied at subordinate points on the Great Lakes in order to obtain a reference datum for engineering, construction, or navigation projects. These hydraulic correctors at gage sites are published by the IJC Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data.

e. Appendix K contains additional technical information on IGLD85 dynamic heights and hydraulic correctors. It also includes an example of a Detroit District navigation project in Lake Superior that is referenced to IGLD85.

CHAPTER 7

Vertical Datums Applicable to Regulatory Permitting

7-1. Purpose and Applicability. This chapter provides general background information on reference elevation grades that may be cited on permit applications or mitigation site plans. ER 1110-2-8160 (*Policies for Referencing Project Elevation Grades to Nationwide Vertical Datums*) notes that vertical reference datums on permit applications should conform to accepted local and state requirements; thus, legacy or local reference datums will usually supersede requirements to reference projects to the NSRS (currently NAVD88) or NOAA NWLON tidal datums. Therefore, the technical guidance in this chapter is intended to cover only those permit applications or mitigation projects where the reference to a nationwide vertical NSRS or NWLON datum may be applicable.

7-2. Vertical Reference Datums Used in Regulatory Activities. Table 7-1 lists some of the reference datums that may be applicable to permitting or mitigation projects. These reference datums are also illustrated in Figures 7-1 and 7-2 and further described in subsequent sections. In tidal areas, established datum limits defined by NOAA are measured based on gage readings—e.g., MSL, MLW, MHW. Reference data at these gages may also be related to NSRS (NAVD88) datums. Limits defined by more subjective observations (OHWM, MHT) do not necessarily have hydraulic or tidal gage measurement definitions; however, OHWM or MHT points or contours on permit applications may have been surveyed relative to established NSRS (NAVD88) datums. Many permit applications reference water surface and excavation/fill elevations to superseded legacy orthometric datums (e.g., NGVD29) under the erroneous assumption this datum relates to the current epoch of LMSL.

7-3. Ordinary High Water Mark (OHWM) Determination. OHWM is a jurisdictional benchmark for administering the USACE regulatory program in navigable waterways under Section 10 of the Rivers and Harbors Appropriations Act of 1899 (33 U.S.C. 403) and Section 404 of the Clean Water Act of 1977 (33 U.S.C. 1344). The term "Ordinary High Water Mark" is defined in 33 CFR 328.3 (*Definitions of Waters of the United States*) to "mean that line on the shore established by the fluctuations of water and indicated by physical characteristics such as clear, natural line impressed on the bank, shelving, changes in the character of soil, destruction of terrestrial vegetation, the presence of litter and debris, or other appropriate means that consider the characteristics of the surrounding areas."

a. OHWM interpretation. Various interpretations of OHWMs exist throughout CONUS, given the subjective site-dependent nature of the definition—e.g., estimated vegetation line limits. For example, a OHWM is also defined as "where the banks of a body of water are relatively steep, the OHWM is coordinate with the limit of the bed of the water; and that, only, is to be considered the bed which the water occupies sufficiently long and continuously to wrest it from vegetation and destroy its value for agricultural purposes."

Table 7-1. Vertical Datums used in Regulatory Permitting Authorities.

Authority [1]	Geographic Area	Activity	Typical Reference Datums
SECTION 10 Rivers & Harbor Act of 1899	Navigable Waters of United States	All work over, through, and under navigable waters (e.g., dredging, docks, beach renourishment)	Ordinary High Water Mark (OHWM) Mean High Tide (MHT) Mean Low Water (MLW)
SECTION 404 Clean Water Act of 1977	Waters of the United States, including Wetlands	Fill (e.g., roads, home sites, beach renourishment)	OHWM High Tide Line (HTL) Vegetation lines
SECTION 103 Marine Protection, Research & Sanctuaries Act	Ocean	Transportation of dredged material for the purpose of ocean disposal	Mean Sea Level (MSL) MLLW NAVD88

[1] References are listed in Section 7-12.

(1) When the river banks are low and flat, OHWM is considered "the point up to which the presence and action of the water is so continuous as to destroy the value of the land for agricultural purposes by preventing growth of vegetation."

(2) On navigable lakes and rivers the U.S. Government holds an easement for riparian lands up to the OHWM. Thus, it is essential that the OHWM demarcation line be referenced to reliable vertical datums—to include the NSRS (NAVD88). In controlled pools, the relationship between the OHWM and pool discharge controlling elevations should be related to a common and consistent reference datum.

b. Open water. Open water is defined as an area that, during a year with normal patterns of precipitation, has standing or flowing water for sufficient duration to establish an OHWM. Aquatic vegetation within the area of standing or flowing water is either non-emergent, sparse, or absent. Vegetated shallows are considered to be open waters. The term 'open water' includes rivers, streams, lakes, and ponds.

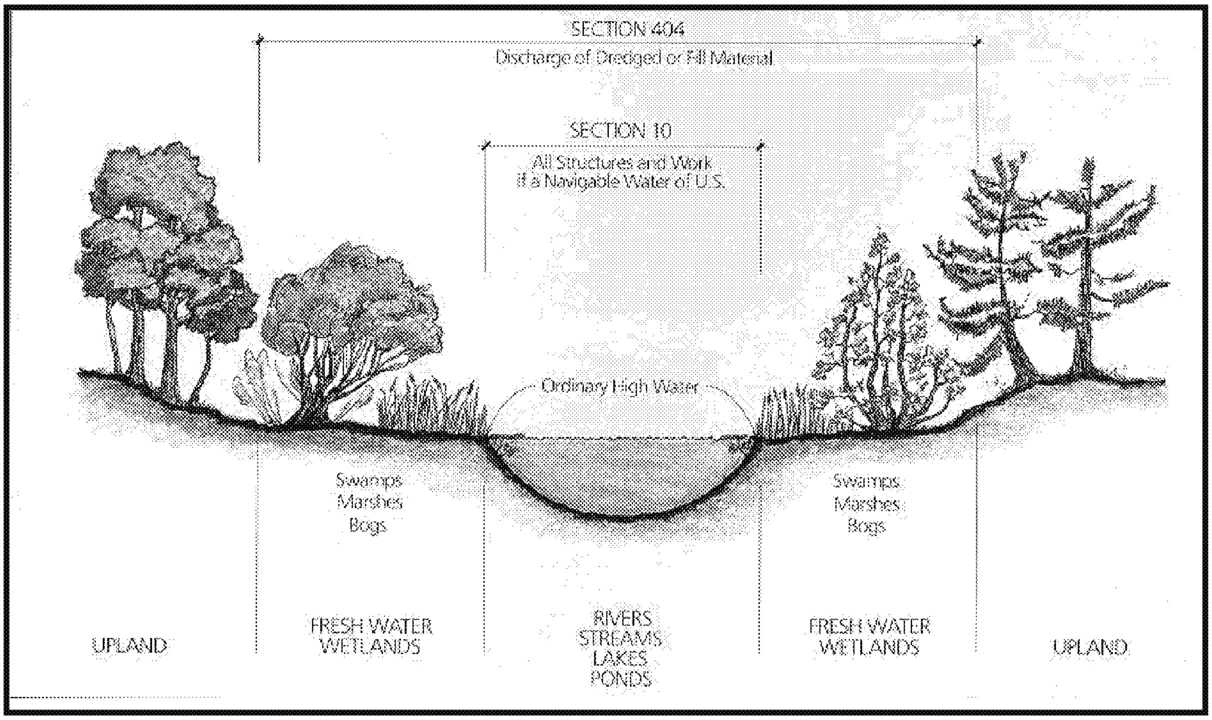


Figure 7-1. Regulatory datums for various permit authorities—inland rivers and lakes.

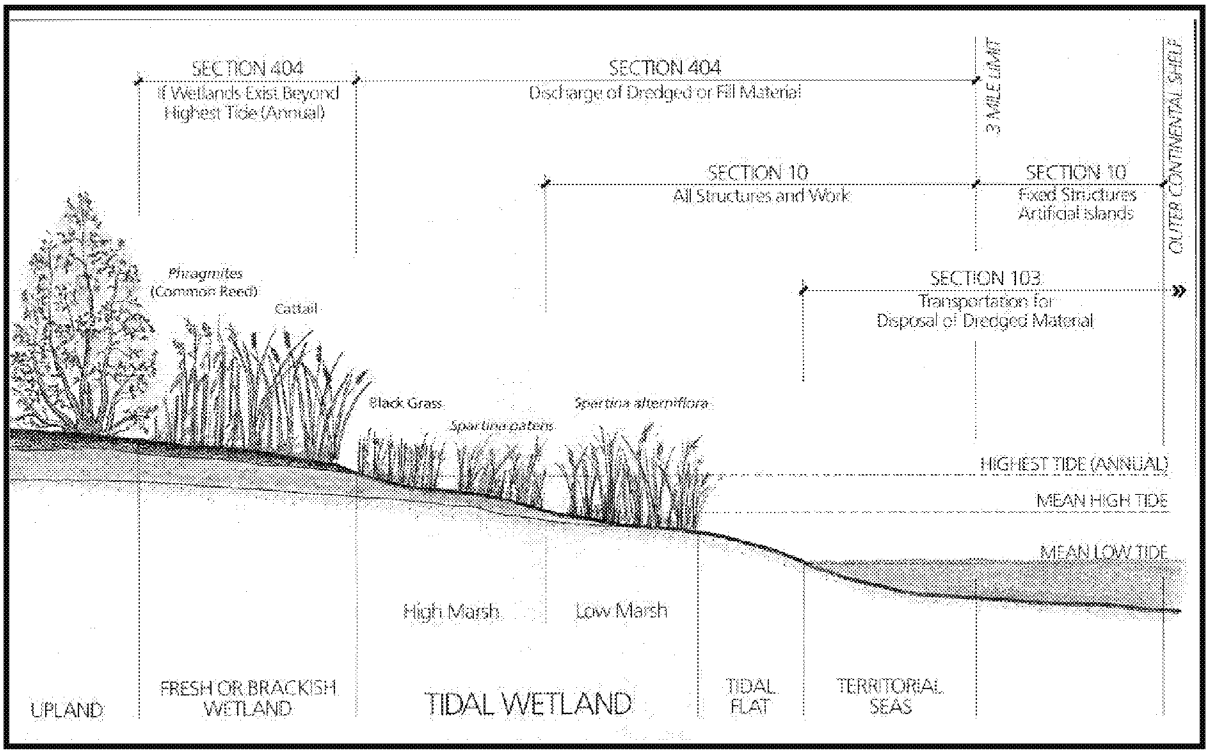


Figure 7-2. Regulatory datums for various permit authorities—tidal areas. In this figure "Highest Tide (Annual)" approximates HTL or MHWS, "Mean High Tide" approximates MHW, and "Mean Low Tide" approximates MLW.

c. Stream bed. A stream bed is defined as the substrate of the channel between the OHWMs. The substrate may be bedrock or inorganic particles that range in size form clay to boulders. Wetlands contiguous to the stream bed, but outside of the OHWMs, are not considered part of the stream bed.

d. Survey methods. Once OHWMs are delineated (staked out) in the field, various survey methods outlined in Chapter 3 may be used to control horizontal positions and elevations. RTK/RTN methods are usually the most efficient and provide adequate accuracy—typically less than ±0.2 ft relative to a nearby vertical reference PPCP—a gage or published NSRS bench mark. OHWM points will usually be marked with TBM hubs. Permanent marks (PBMs) will often be offset (set back) from the OHWM to higher ground, similar to erosion control lines or construction setback lines. Elevations will normally be referenced to NAVD88; however, legacy elevations or river/pool stages may be used. The horizontal location of OHWMs will normally be referenced to the local site plan (e.g., local boundary corners and structures). NAD83 coordinates may also be referenced on the site plan, either SPCS or geographical.

e. Example. Figure 7-3 is an example from a permit application that adequately references the proposed structure elevation to the local IGLD85 and NAVD88 datums at Lake Michigan. The relationship between the datums is clearly indicated on the drawing. Also shown is the established OHWM at the project site—in this case, differing federal and state OHWM determinations.

7-4. High Tide Line (HTL) and Related High Water Definitions. The high tide elevations depicted in Figure 7-2 are not consistently defined or measured throughout CONUS. High water tidal reference datums may be based on observed gage data, predicted tide models, or, in some cases, on visual estimates. Tidal datums based on reduced observations from federal or state gages are the most reliable and defensible. Predicted high tide levels based on NOAA models (TCARI, VDatum, etc.) would be next in reliability. Estimated tidal datum levels would be the most difficult to authenticate.

a. 33 CFR 328.3 definition of High Tide Line. The term "High Tide Line" (labeled as "Highest Tide Annual" in Figure 7-2) is defined in 33 CFR 328.3 as "... the line of intersection of the land with the water's surface at the maximum height reached by a rising tide. The HTL may be determined, in the absence of actual data, by a line of oil or scum along shore objects, a more or less continuous deposit of fine shell or debris on the foreshore or berm, other physical markings or characteristics, vegetation lines, tidal gages, or other suitable means that delineate the general height reached by a rising tide. The HTL encompasses spring high tides [MHWS] and other high tides that occur with periodic frequency but does not include storm surges in which there is a departure from the normal or predicted reach of the tide due to the piling up of water against a coast by strong winds such as those accompanying a hurricane or other intense storm."

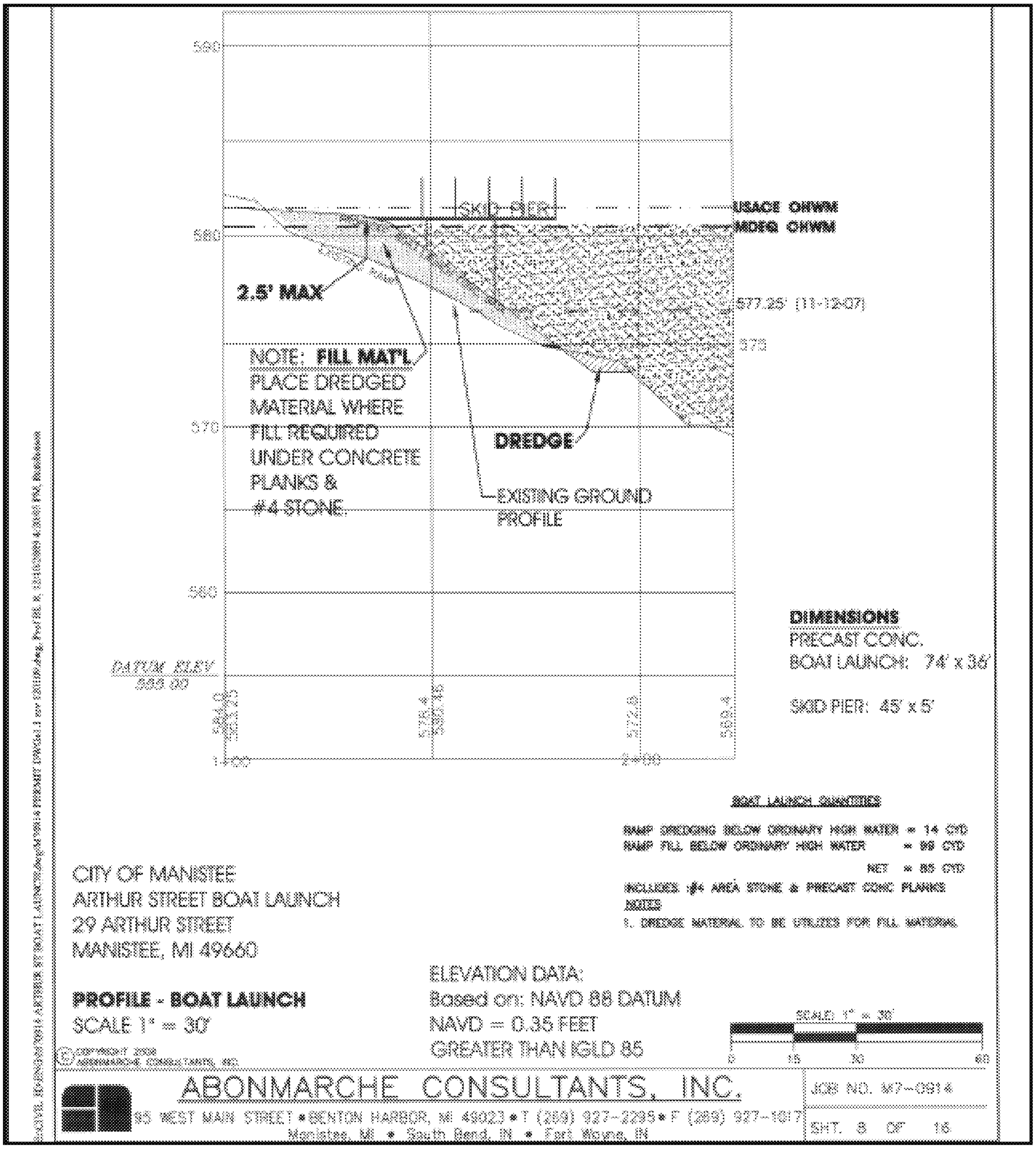


Figure 7-3. Federal (USACE) and State (Michigan Department of Environmental Quality) OHWM datums at Manistee, Michigan permit application site. (USACE OHWM—elevation 581.5 ft). Note that NAVD88 is 0.35 ft greater than IGLD85 (577.5 ft). (Detroit District)

(1) The preceding 33 CFR 328.3 definition implies High Tide Lines may be based on measured Spring Tides—i.e., Mean High Water Springs, or MHWS—at a local gage station.